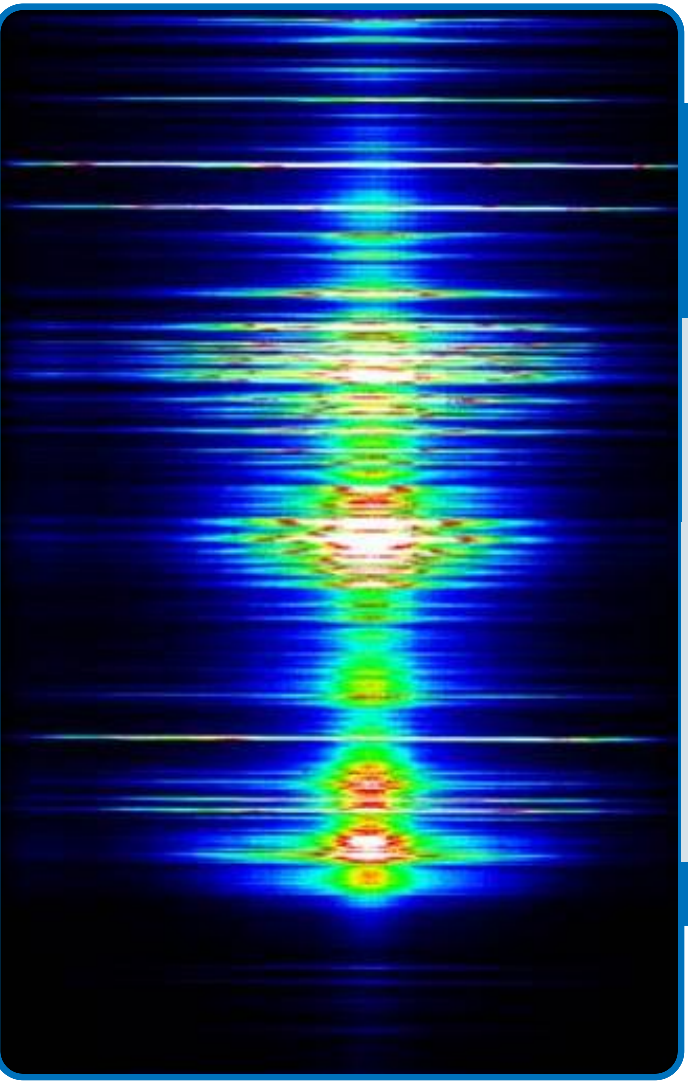

XUV and EUV Applications with EUV Sources for Metrology

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Christoph Phiesel,
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History on EUV Sources: DPP & LPP !

JOURNAL OF APPLIED PHYSICS VOLUME 83, NUMBER 9 1 MAY 1998

Narrowband laser produced extreme ultraviolet sources adapted to silicon/molybdenum multilayer optics

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(Received 28 May 1997; accepted for publication 21 January 1998)

The extreme ultraviolet radiation emitted from a plasma generated by a pulsed Nd:yttrium aluminum garnet laser is investigated around 13 nm wavelength for several low Z elements (lithium, nitrogen, oxygen, fluorine). A narrowband EUV source can be designed by using the narrowband line emission of low Z elements in combination with the broadband reflection characteristic of silicon/molybdenum (Si/Mo) multilayer mirrors. Experimental results are discussed within a theoretical model, which allows a deduction of an optimization criterion for a maximum conversion efficiency. The Lyman-α line of hydrogenlike lithium ions fulfills the demands for high intense, free-standing narrowband emission at the long wavelength side of the silicon absorption L edge. [S0021-8979(98)00909-8]

I. INTRODUCTION

Radiation in the extreme ultraviolet (EUV) region is of great interest for the future technology of producing and analyzing structures on the nanometer scale. Beside synchrotron radiation sources, table top EUV sources like laser produced plasmas are under investigation for laboratory applications. Intense laser radiation creates a hot dense plasma by interaction with the surface of a target. These plasmas emit radiation in the EUV wavelength region. To adapt the spectral distribution of the radiation of laser produced plasmas to Si/Mo multilayer optics, appropriate target material has to be selected. High conversion efficiency can be reached by adaptation of the laser parameters.

Plasmas of high Z elements emit radiation with a continuous spectral distribution. They are under investigation for EUV projection lithography[1–3] because of the high conversion efficiency for broadband radiation.[4,5] Several analytical applications, however, require narrowband radiation. This can be generated by broadband radiation in combination with monochromators. An alternative is the coarse filtering of an emission line of low Z element plasma. The number of electron transitions in these highly ionized atoms is low and the emitted spectral lines of these plasmas are well separated.[6]

Especially, chemical analysis of structured surfaces can be done by lateral resolved x-ray photoelectron spectroscopy (XPS) using EUV radiation. For high energy resolution of this method a narrowband EUV source is needed. For high lateral resolution the radiation has to be focused to a small spot onto the surface of a sample, for example, by multilayer mirrors. Furthermore, pulsed radiation enables a time-of-flight (TOF) detection of the generated electrons. Using TOF, an image of the electron energy spectrum can be obtained over a wide spectral range.[7]

Si/Mo multilayer mirrors consists of a stack of alternating thin films of silicon and molybdenum. The period thickness is adapted to the wavelength and the incidence angle of the radiation by Braggs law.[8] High reflectivity is reached for radiation at the long wavelength side near to the silicon absorption L edge at $\lambda \geq 12.4$ nm, $E_{ph} \leq 100.6$ eV, respectively. These mirrors reflect a wavelength band of about 0.5 nm width depending on the number of periods.[8,9] In combination with an emitter of free standing lines a multilayer mirror makes monochromators dispensable.

For EUV technology in general and especially XPS requirements, the combination of laser produced plasmas as pulsed, highly intense EUV sources and Si/Mo multilayer mirrors as efficient reflectors is well suited.

II. TARGET SELECTION

The photon energy of the emitted radiation depends on the target element, the ionization state, and the electron transition. The ionization state and population of the shells are determined by the plasma temperature and density, which can be tuned by the laser parameters intensity, wavelength, and pulse duration.

Figure 1 shows the dependence of the atomic number of the element and the electron transition on the photon energy of the emitted radiation. The photon energy region around the silicon absorption L edge at 100.6 eV is enlarged. We only consider inner shell transitions between shells with quantum numbers $n \leq 4$, because their population in the thermal equilibrium is higher compared to shells with higher quantum numbers.[10]

On the low energy side of the silicon absorption L edge within an energy range from 80 to 100 eV the transitions of hydrogenlike lithium and nitrogen and lithiumlike oxygen and fluorine can be identified (Table I). The emission lines of the lithiumlike ions are split by the different J transitions into a doublet. The transition energies of heliumlike beryllium ($Z=4$) and higher Z elements are on the short wavelength side of the silicon L edge where the absorption of silicon is high.[11] For this reason the radiation is not suited for Si/Mo multilayer application. However, it might be of interest for reflection with rhodium/beryllium multilayer mirrors.

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ELSEVIER Microelectronic Engineering 46 (1999) 449–452

MICROELECTRONIC ENGINEERING

A gas discharged based radiation source for EUV-lithography

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A new high repetitive, compact and low cost gas discharge based EUV „lamp" has been studied as an alternative to laser-produced plasmas as EUV sources. First results using oxygen in a fast discharge of electrically stored energy around 1 J lead to a conversion efficiency of about 0.1 % for the emission at 13.0 nm which is suited for the use with Mo/Si-multilayer mirrors. Using Xenon a broadband emission in the investigated wavelength range from 10 nm to 18 nm is observed. With a first version a source with 40 W electrical input power could be demonstrated that emits about 50 mW/(4πsr) around 13 nm at a repetition rate of 150 Hz. No debris and no electrode erosion was observed after more than 10^7 pulses done up to now. Making use of the remaining optimisation potential this concept seems to be promising to fulfil the requirements of extreme-ultraviolet lithography

1 INTRODUCTION

Extreme-ultraviolet (EUV) lithography used for the future generation of semiconductor devices requires compact radiation sources around a wavelength of 13 nm, which emit up to 20 W in a bandwidth of 2 eV [1]. Up to now the main interest has been devoted to laser-produced plasmas as EUV sources [2-4]. Using such sources in combination with multilayer mirrors the production of structures around 100 nm has been successfully demonstrated [5,6]. However, there are still problems in achieving the required average radiation power. These problems are mainly in reducing the debris of the plasma source and in standing by the high power laser systems. In this work a new kind of gas discharge based EUV source is presented where the problems of reproducibility, operation at a sufficient high repetition rate and the limited lifetime known from other gas discharge based EUV sources, e.g., the capillary discharge [7] or Z-pinches have been solved. In comparison to laser-produced plasma sources the gas discharge plasmas offer the advantages of a higher wall plug efficiency for the EUV radiation, lower apparative effort and a reduced debris problem.

The principle of the radiation source presented in this paper is similar to a small Z-pinch or a gas filled capillary discharge. However, the special design of the electrodes allow for a repetitive operation and a long lifetime due to low electrode erosion. In contrast to the other concepts a switch is omitted which leads to a better coupling of the electrical energy to the discharge plasma and a lower apparative effort.

2 EXPERIMENTAL SET-UP

The pinch plasma is created by a fast discharge of a charged capacitor. This discharge leads to a pulsed current with a rise time in the range of about 100 ns and peak values in the range of several kiloampere. The current compresses and heats the neutral gas to a plasma with an electron density in the range of 10^{18} cm^{-3} and a temperature of several 10 eV which is appropriate to achieve emission around 13 nm.

The electrically stored energy per pulse is in the range of only a few Joule. A low inductive design of the electrical connections and the omitting of a switch allows to achieve the required current amplitudes with such low storage energies and ensures an optimal conversion of the electrical energy to the plasma.

The special design of the electrodes lead to a low erosive and highly repetitive mode of operation as will be shown below. The typical dimension of such

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Studies on EUV metrology source stability, cleanliness, integration: Paths to increased brightness sources

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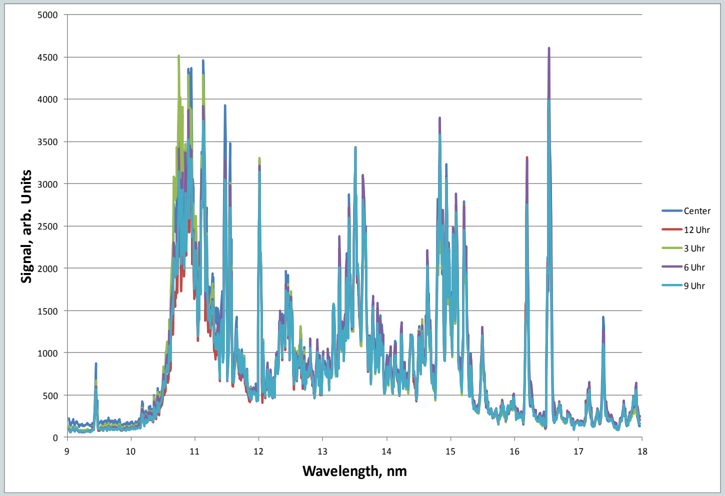
Discharge Produced :

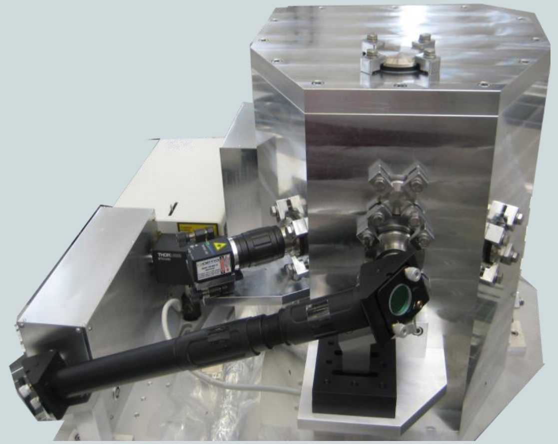
EUV-Lamp < 1 W EUV ib

EUV-Source > 10 W EUV ib



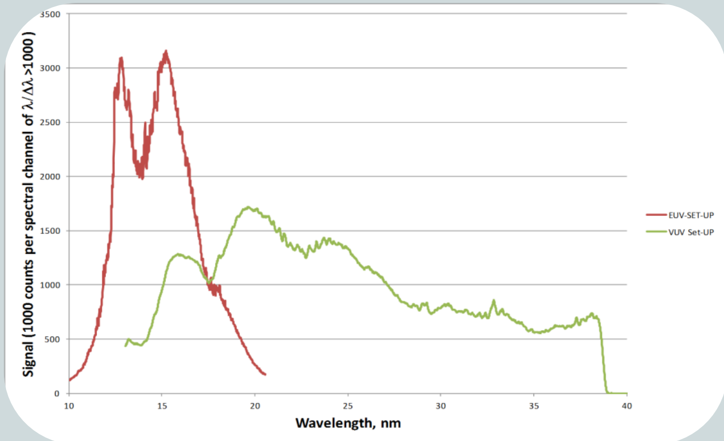
Isotropy of emission spectrum of Xenon from EUV-Lamp under different angles

Laser Produced :



LPP < 10 mW EUV i.b. for spectr.

PoC Set UP HB-LPP



LPP source **gold emission spectrum as** supplied from our partner LzH f**or spectrophotometer**

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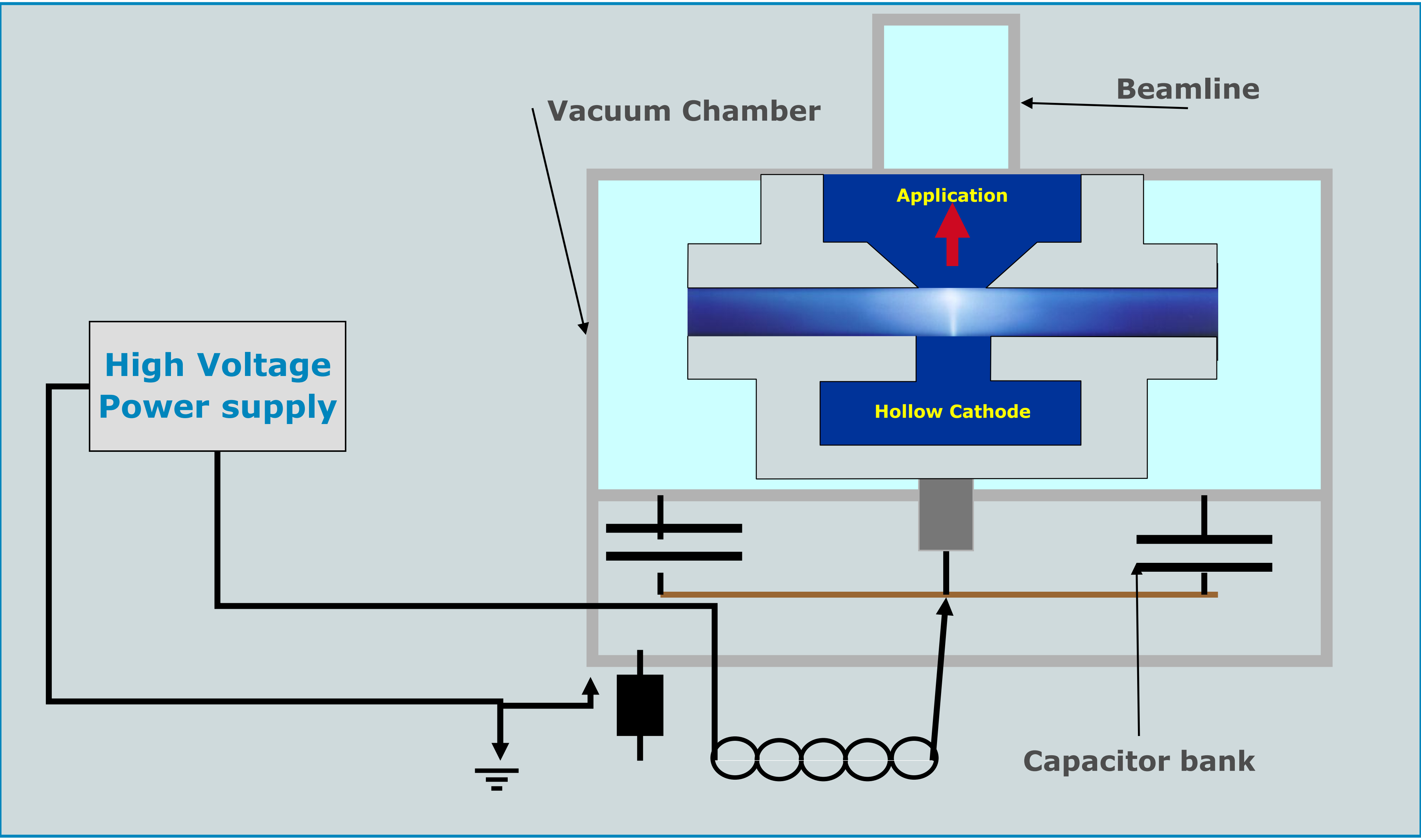
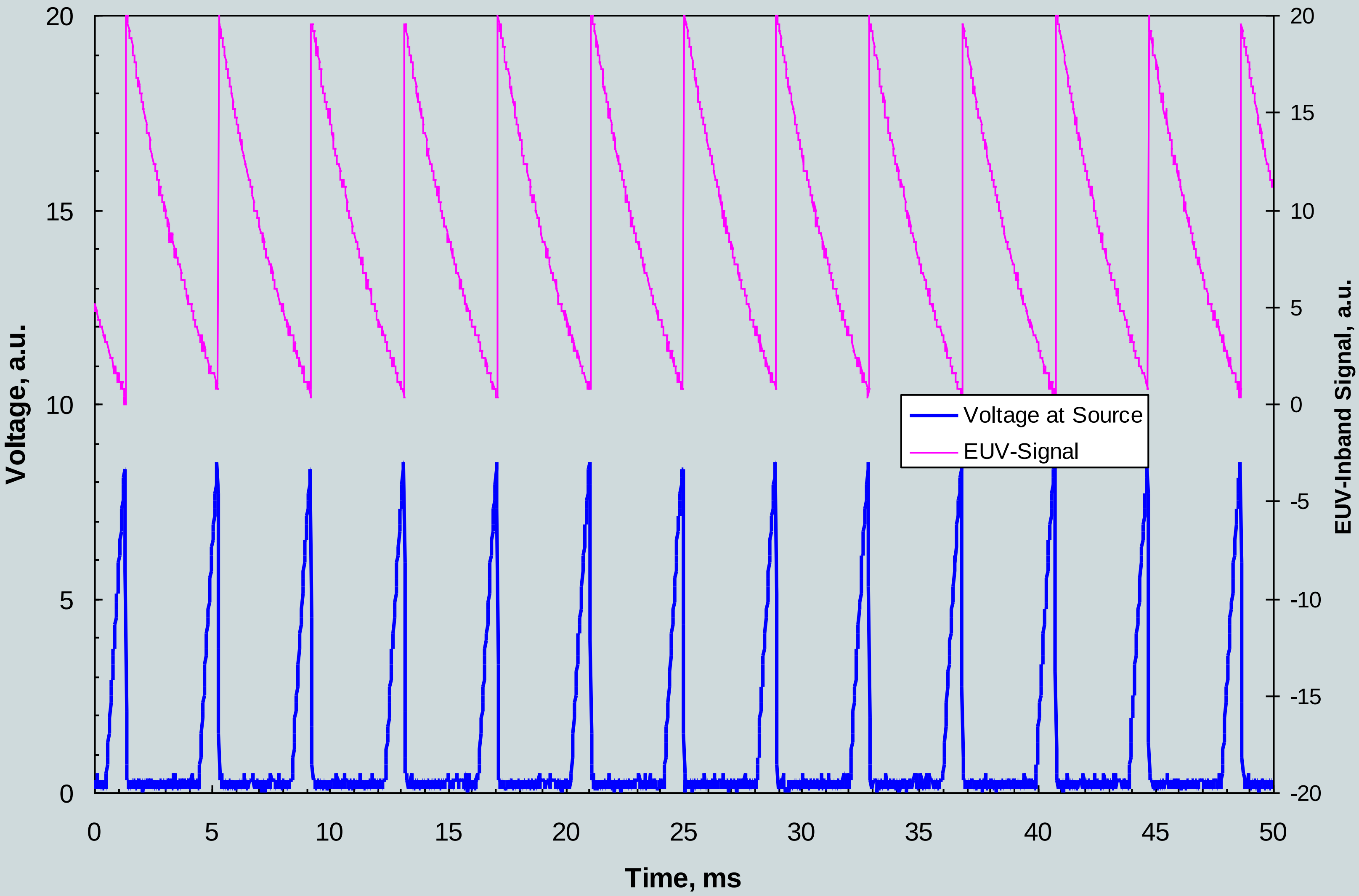
DPP Source Systems

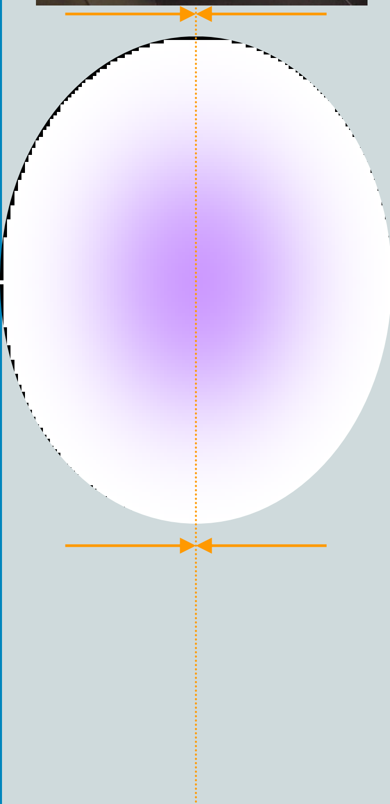
EUV-Lamp Principle

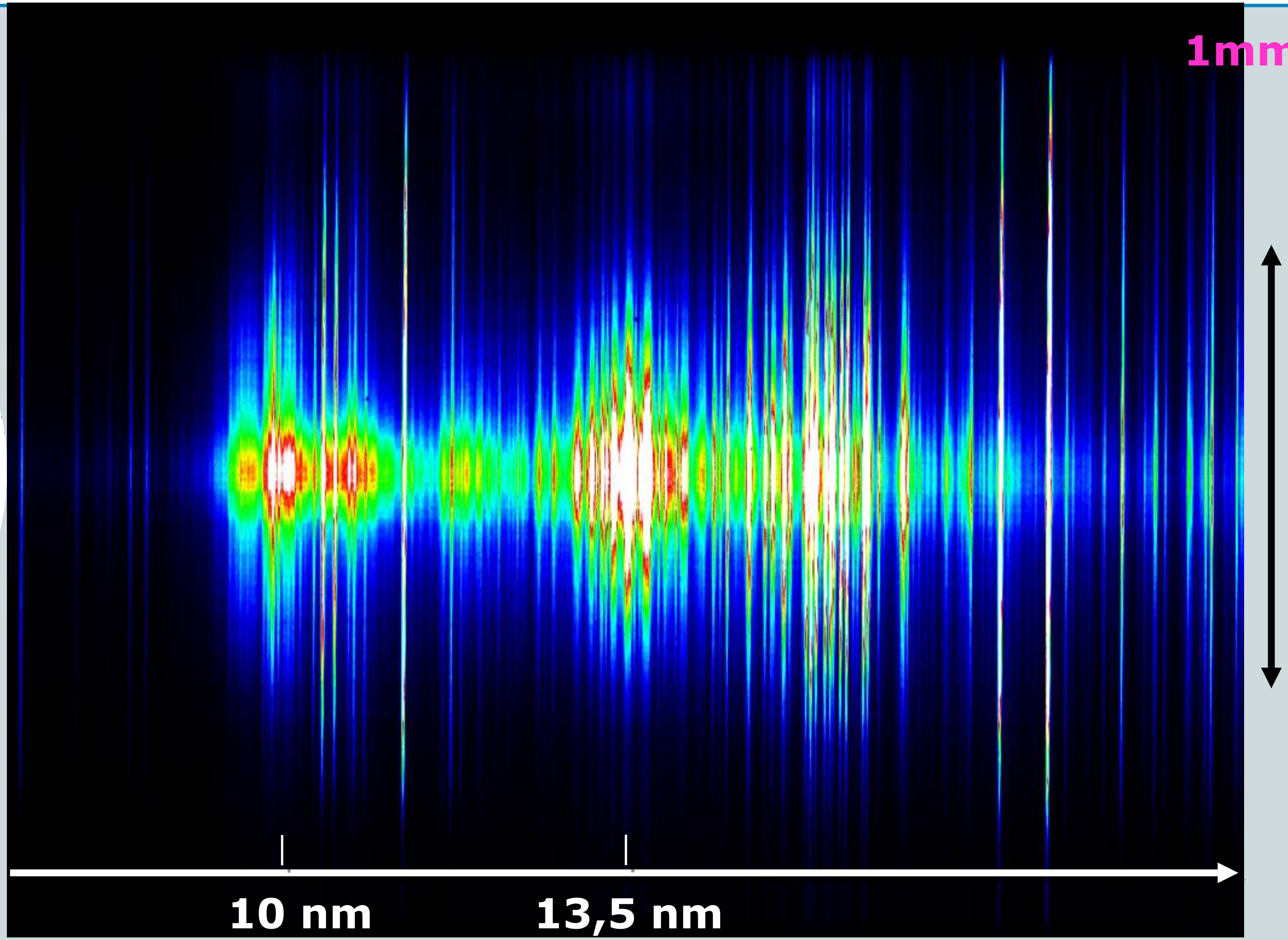


EUV Discharge Lamp Operation

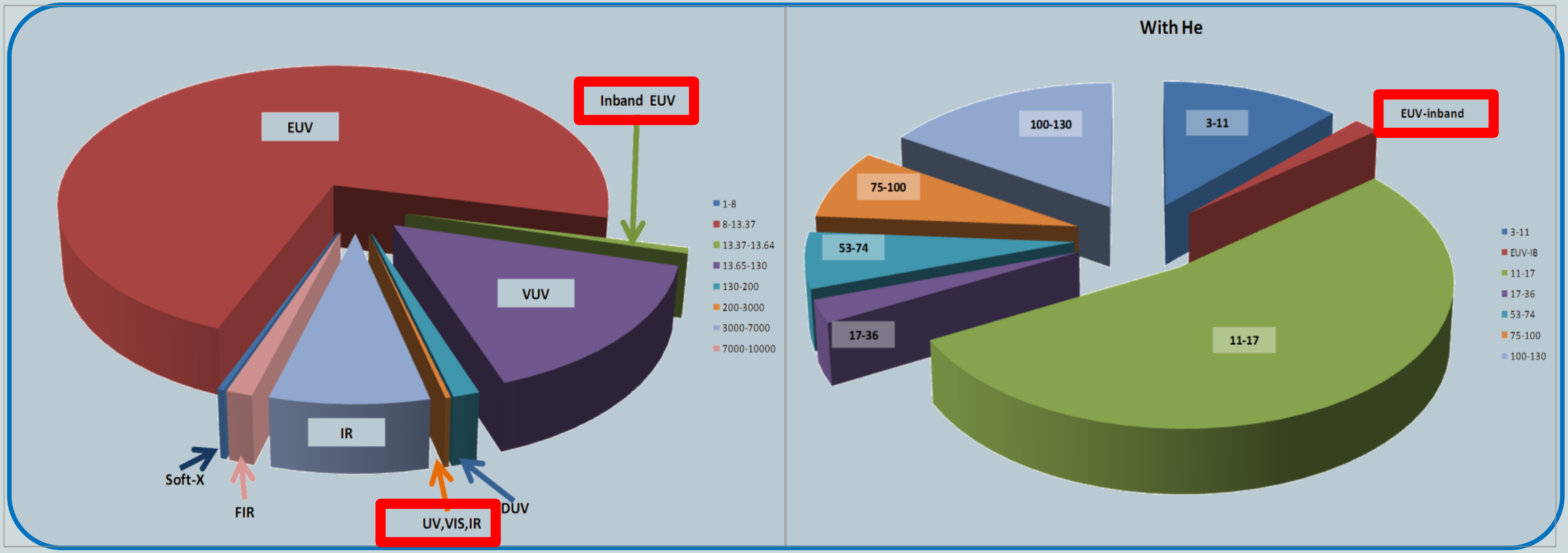


Spatial distribution (spectral resolved)



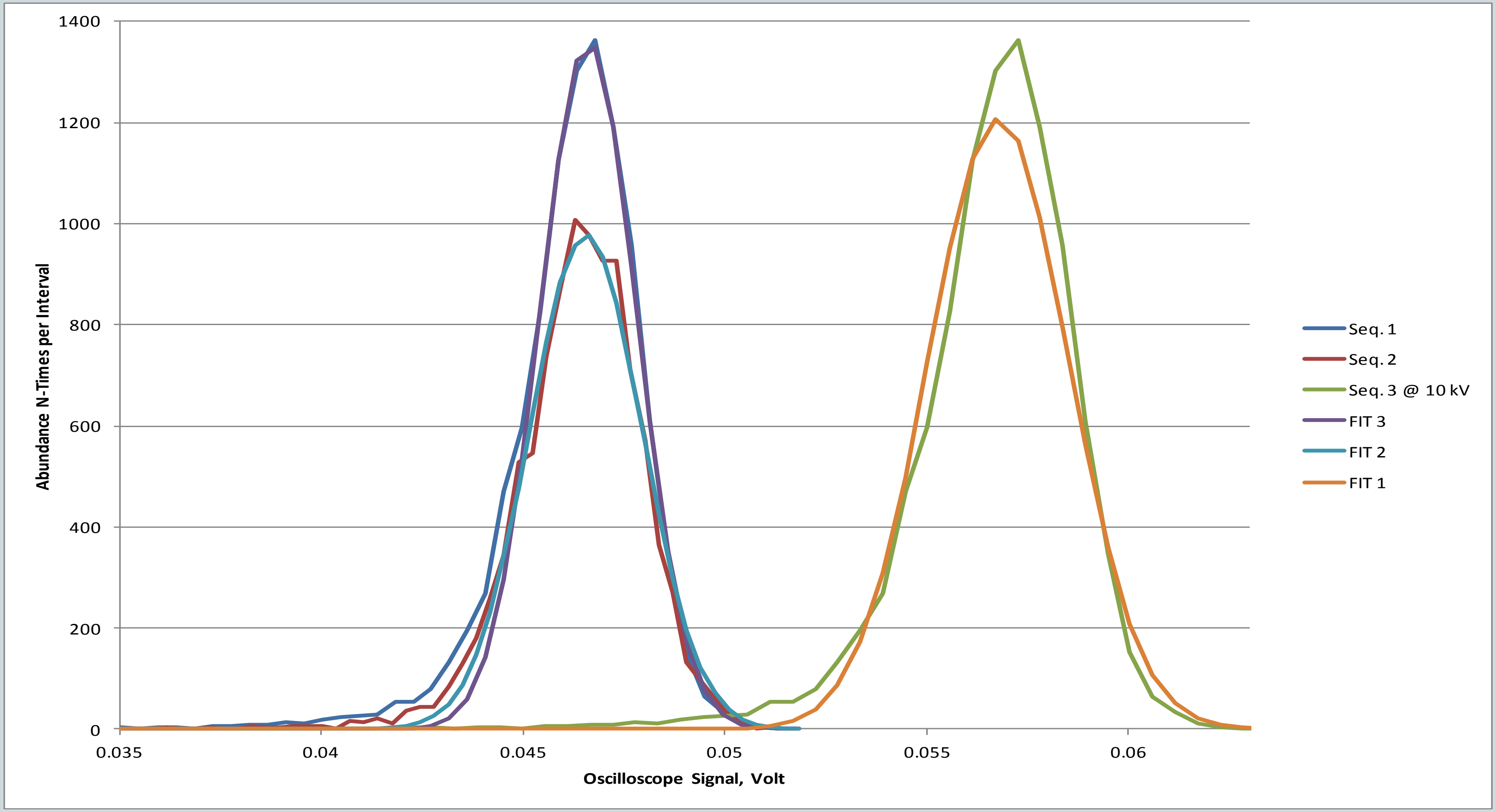


EUV Lamps emit mainly EUV ! But little inband EUV



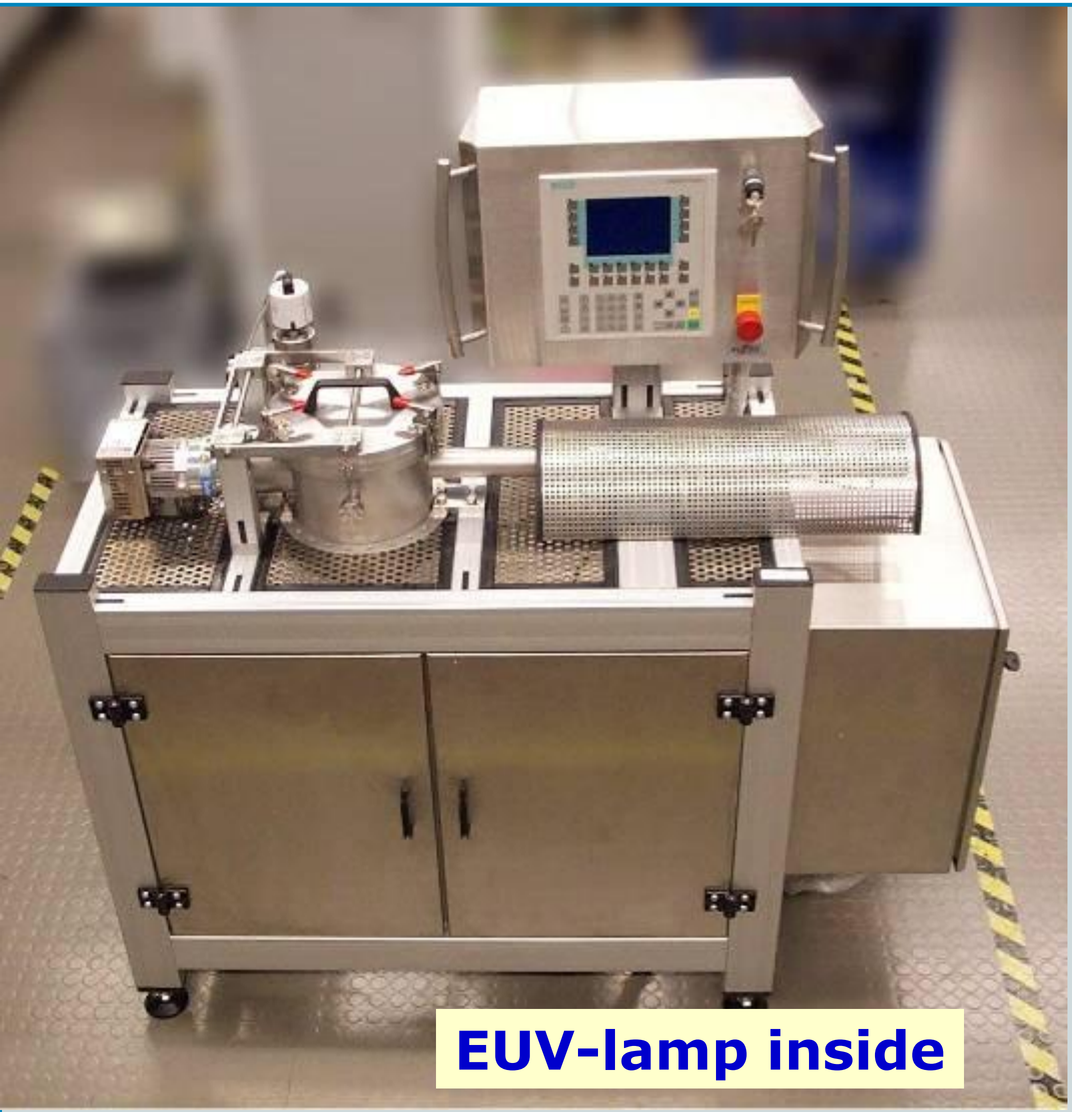
Quantified distribution of emission over spectral channels as measured at EUV-Lamp.

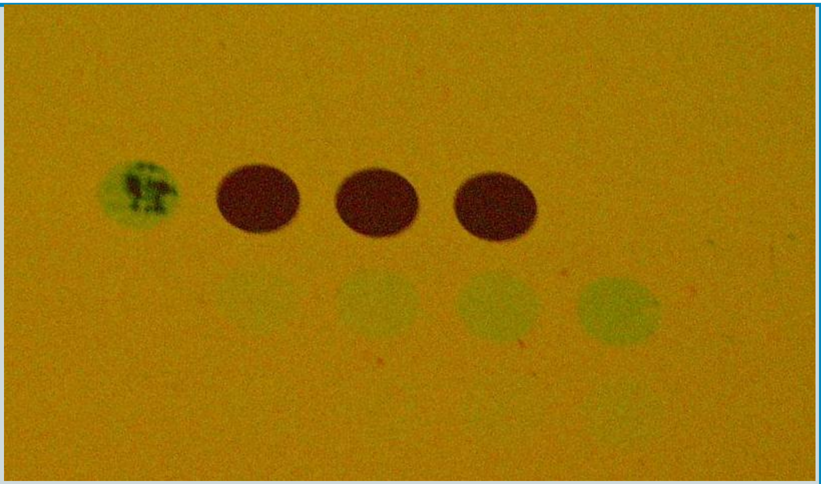
Pulse Statistics DPP

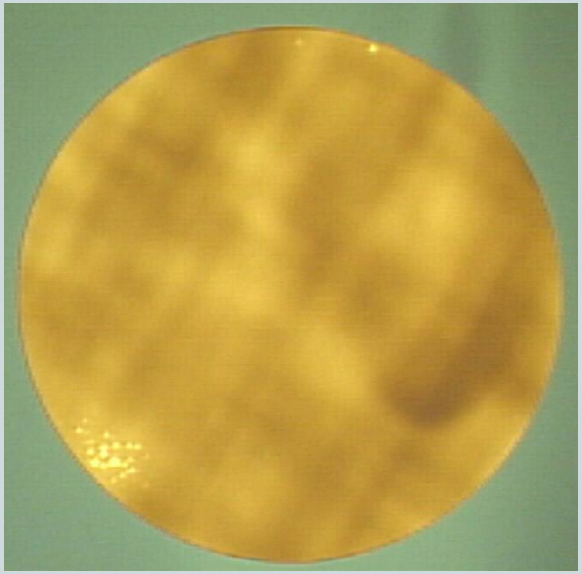


Best-Fit : STDEV =4.3 %, 4.2% und 3.6 %

EUV-inband Open Frame Resist Exposer TEUVL







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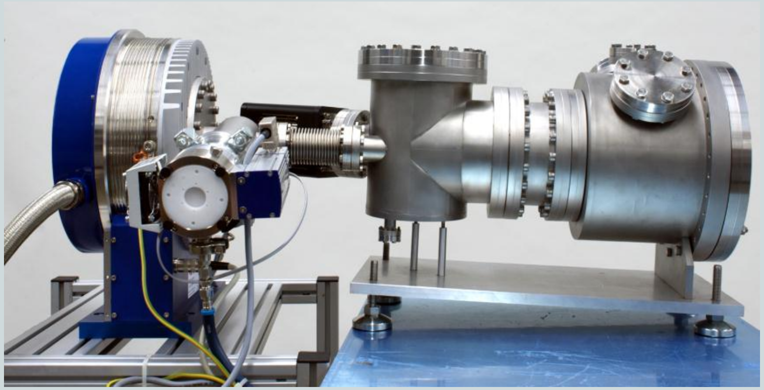
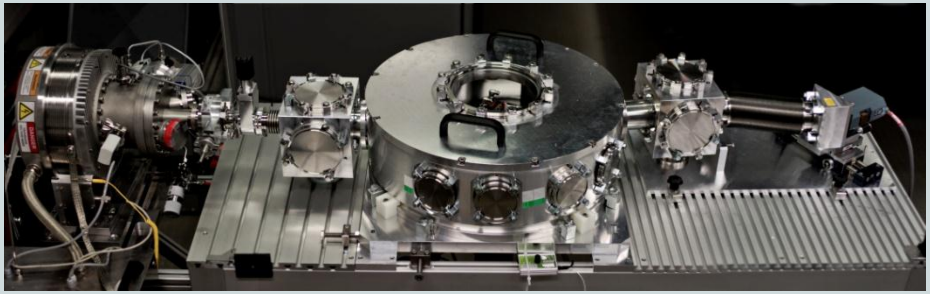
EUV, XUV & VUV Spectroscopy

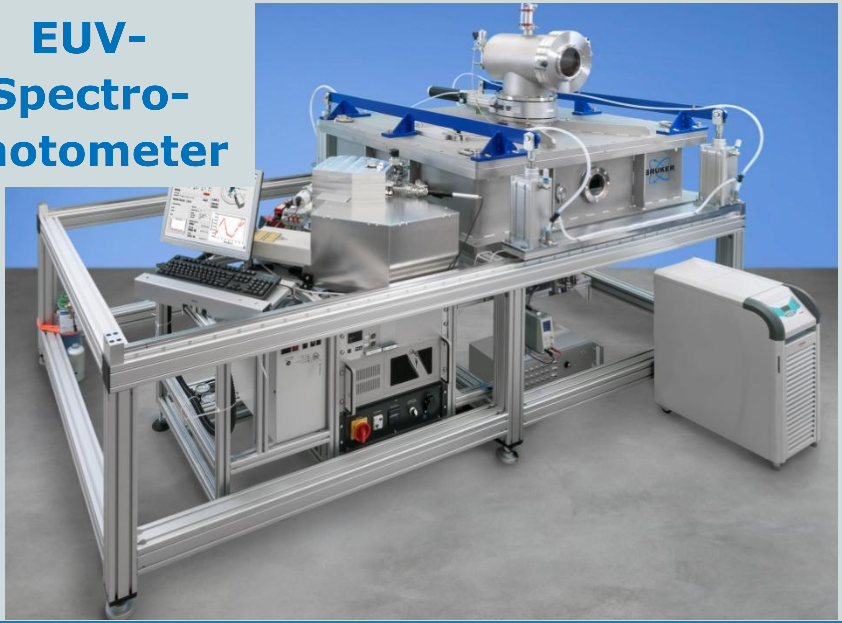
NI R&D EUV Reflectometer



GI R&D EUV Reflectometer

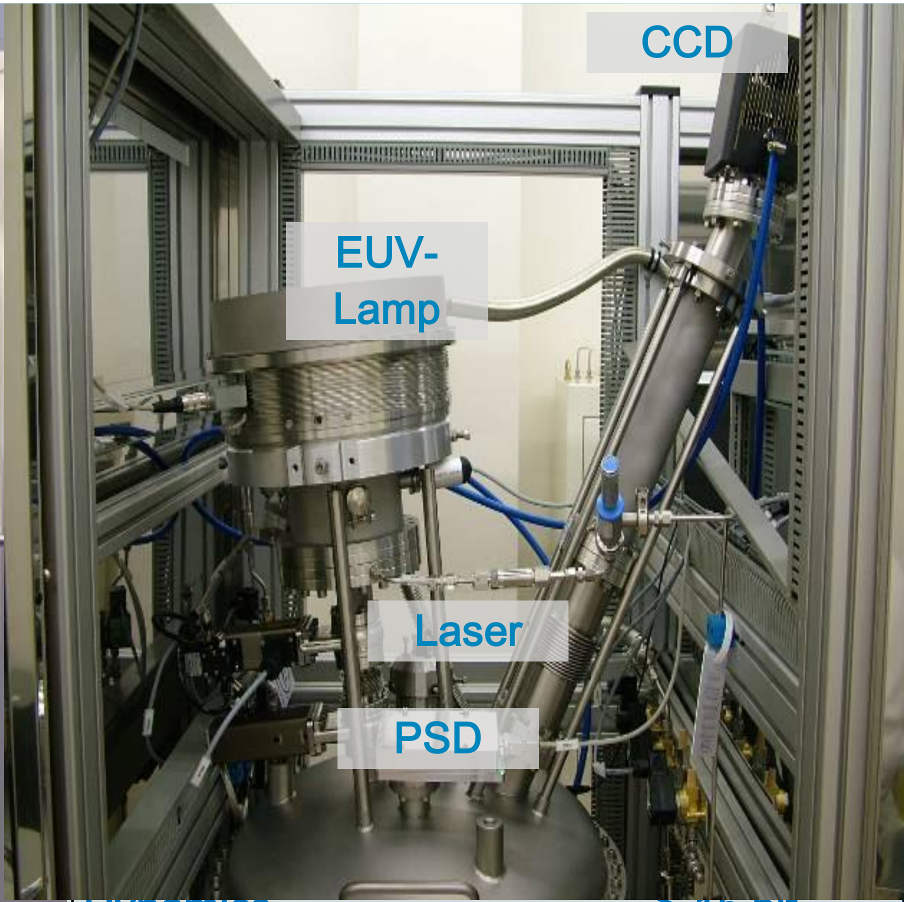


EUV-Spectro-photometer



EUV-MBR

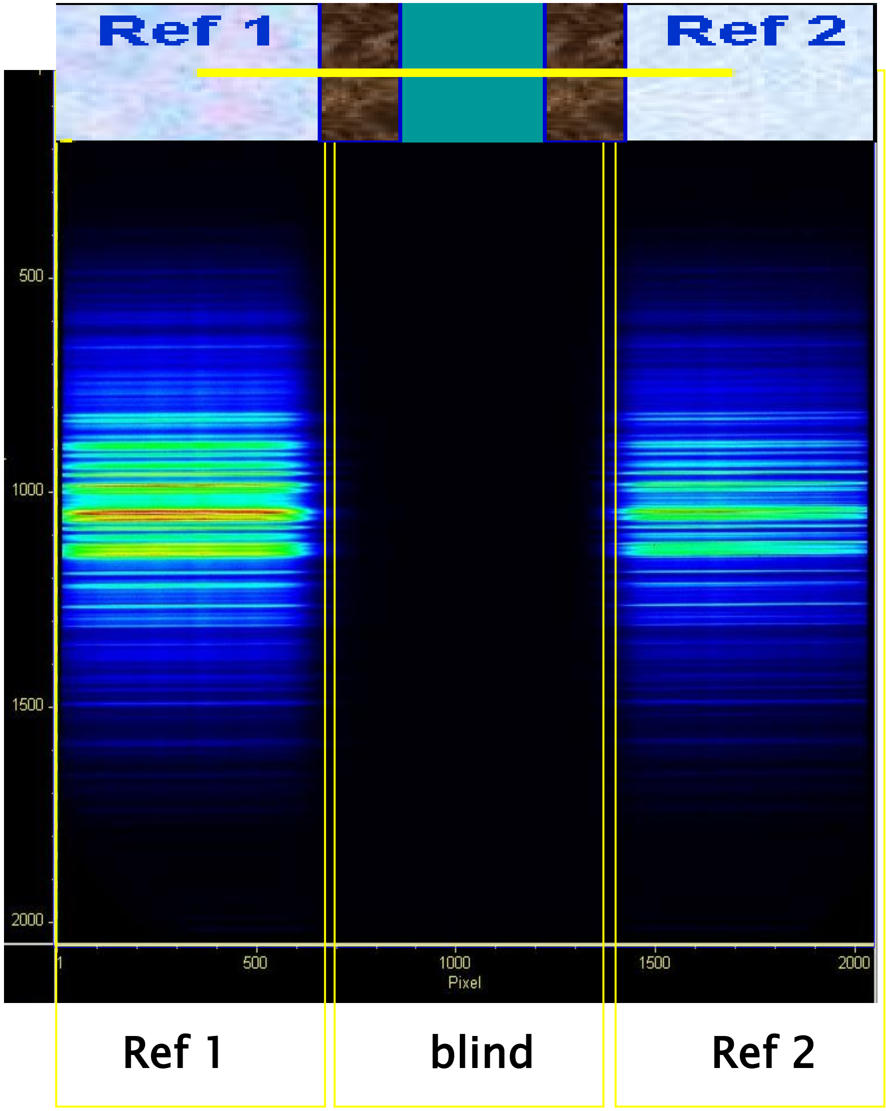
Precise Multilayer Metrology:
EUV-Reflectometer Mask Blank Reflectometer : MBR

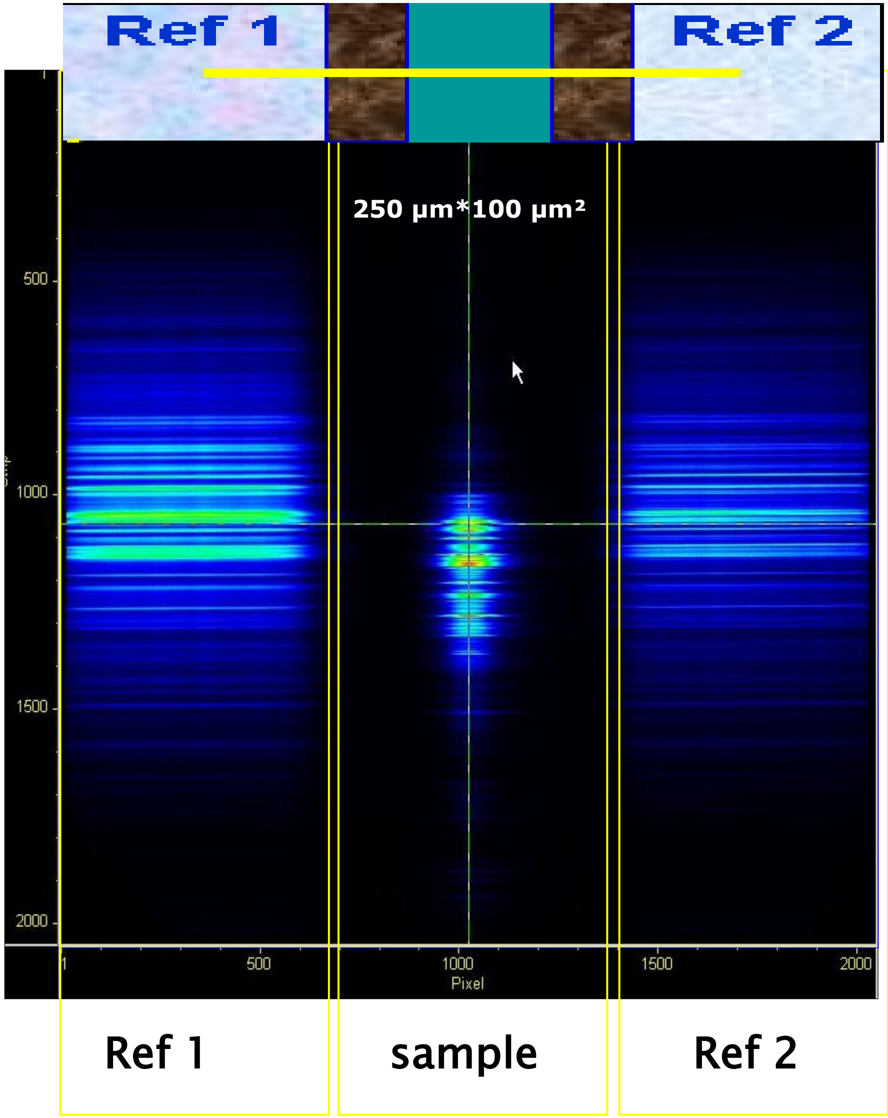


Dynamics > 15 bit

EUV-Lamp: e.g. > 300 Mpulses
> 100 k spots (> 30M 10 pm Channels)
> 10.000 blanks with 9 spots

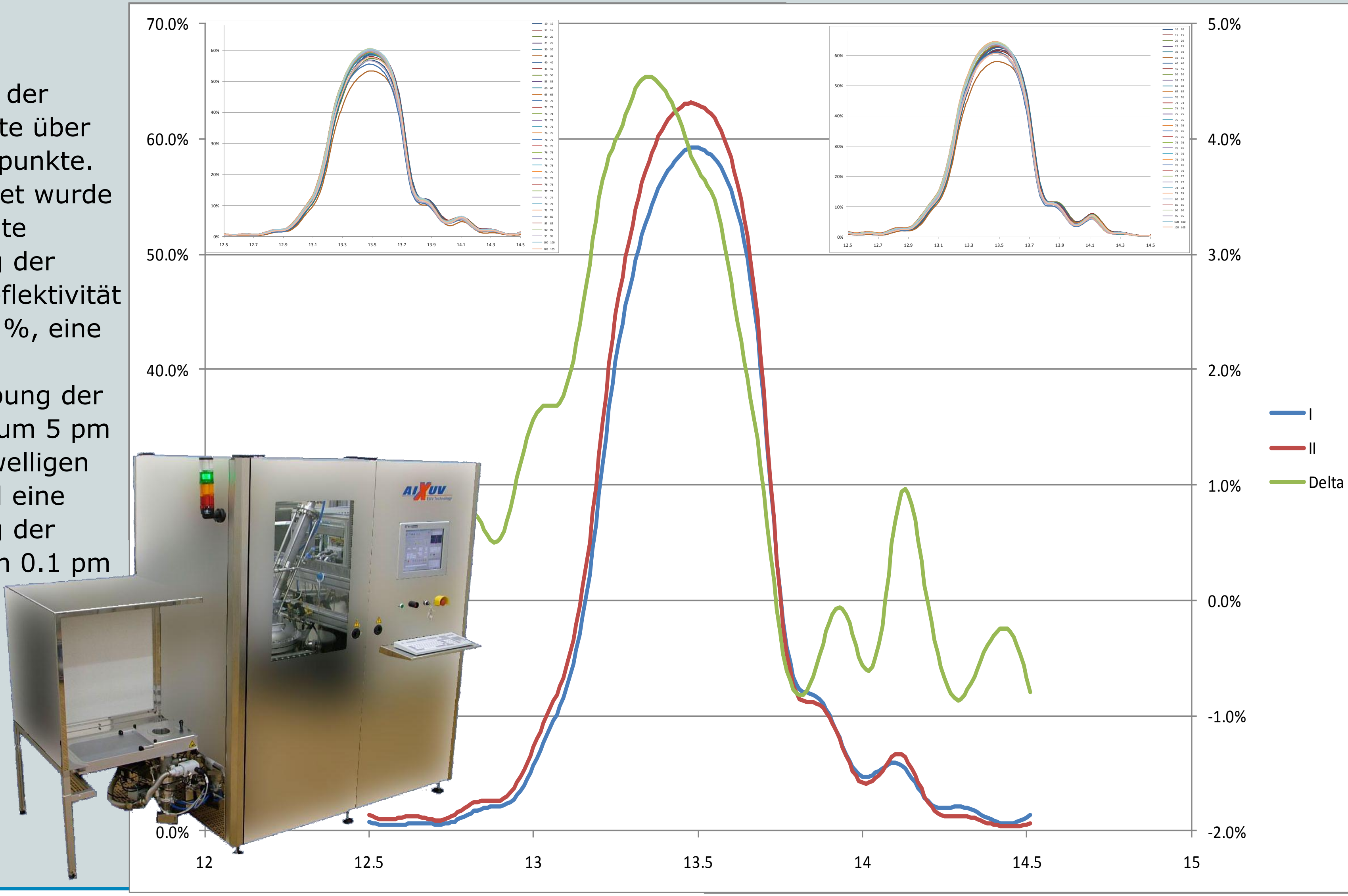
EUV-MBR: in tool reference parallel to sample





Reflektometrie Stand:
Vergleich Maskenblank vor und nach Reinigung

Vergleich der Mittelwerte über alle Messpunkte. Beobachtet wurde eine leichte Erhöhung der Spitzenreflektivität um ca. 2 %, eine leichte Verschiebung der CWL_50 um 5 pm zur kurzwelligen Seite und eine Erhöhung der FWHM um 0.1 pm im Mittel.



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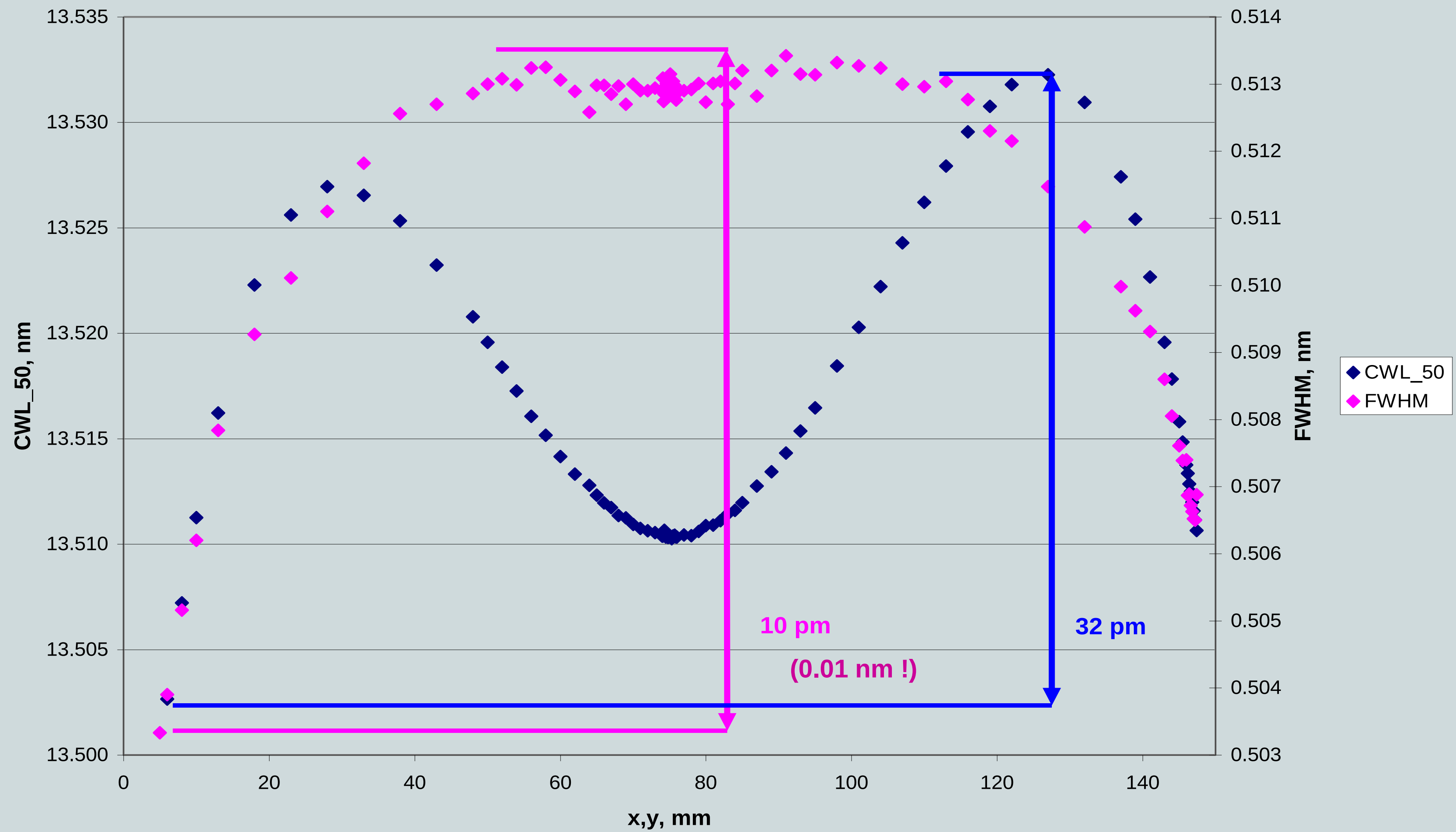
MBR Sensitivity: Diagonal Scan over Mask Blank



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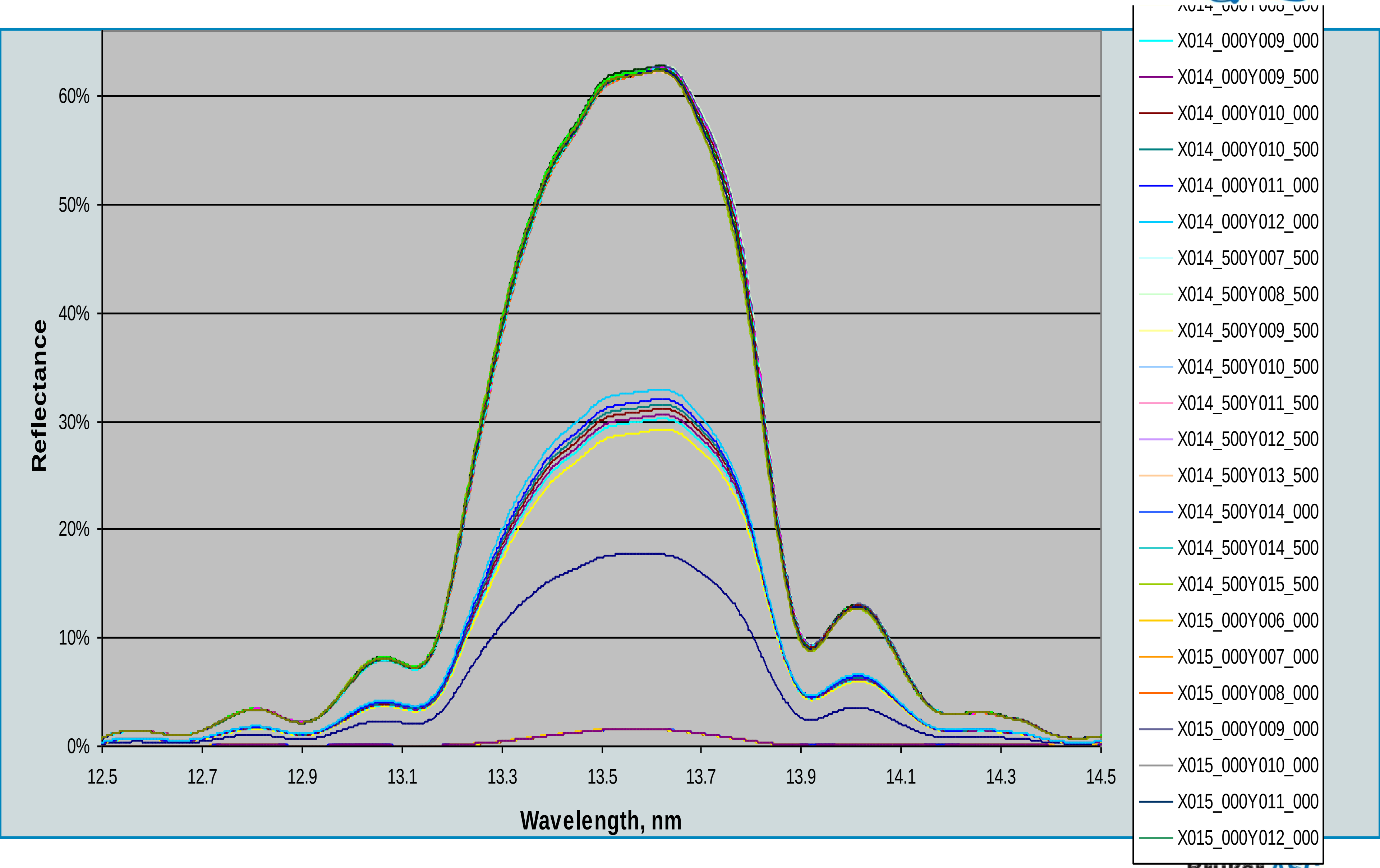
Stepping Measurement over Structured Mask



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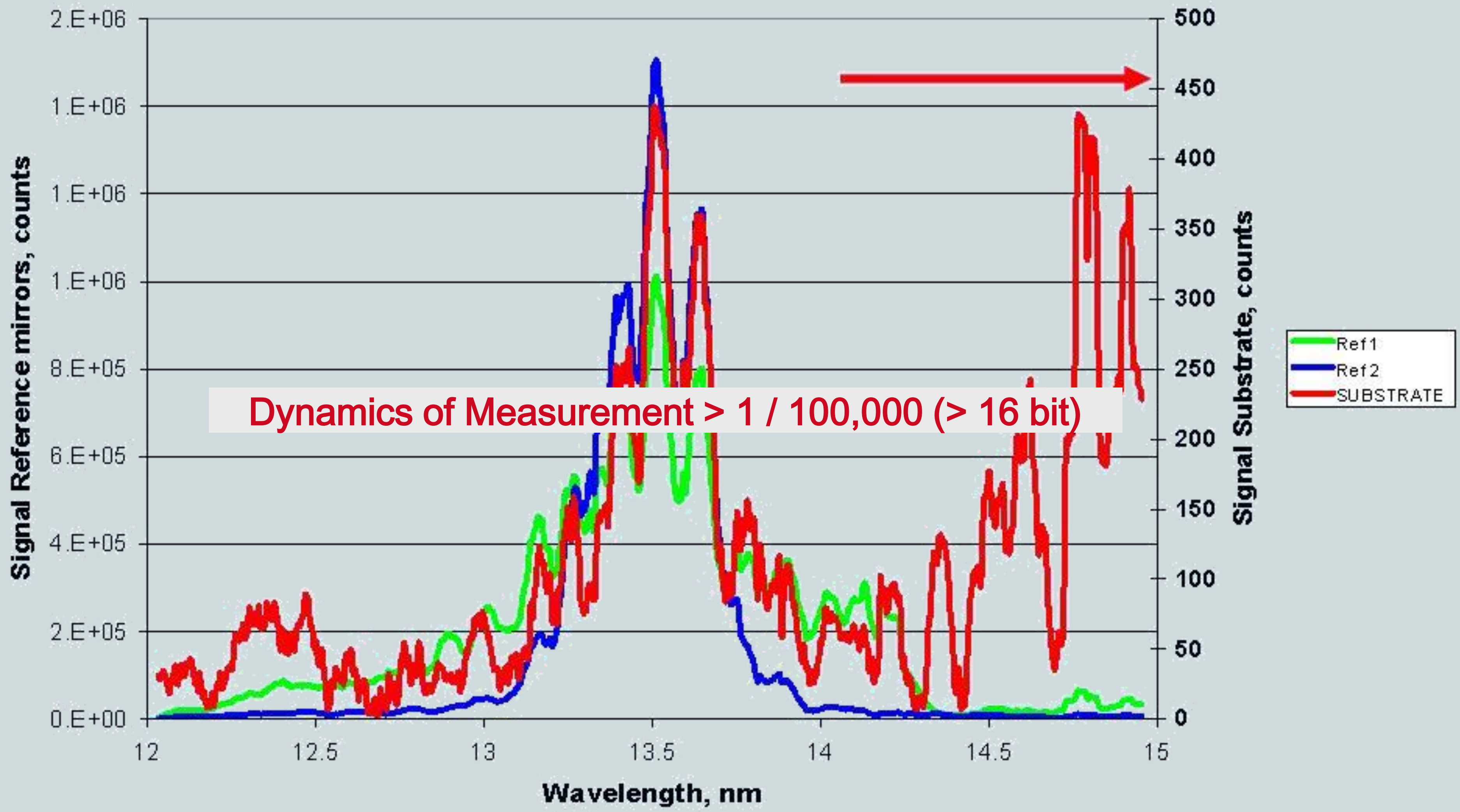
Limit of Measurement: Reflection from Substrate



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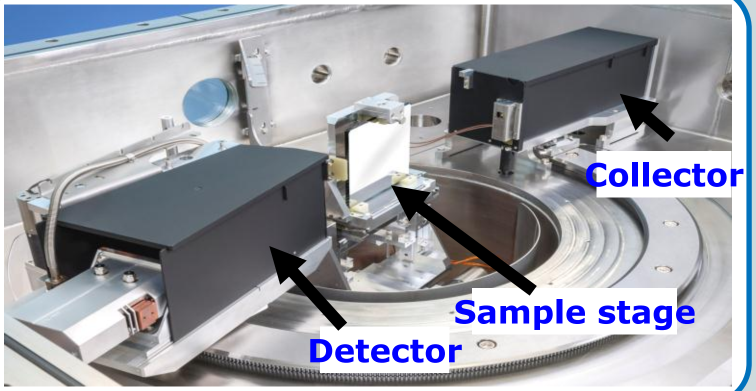
Improvements and extensions on actinic spectral metrology :

Concept for flexible spectral characterization of samples

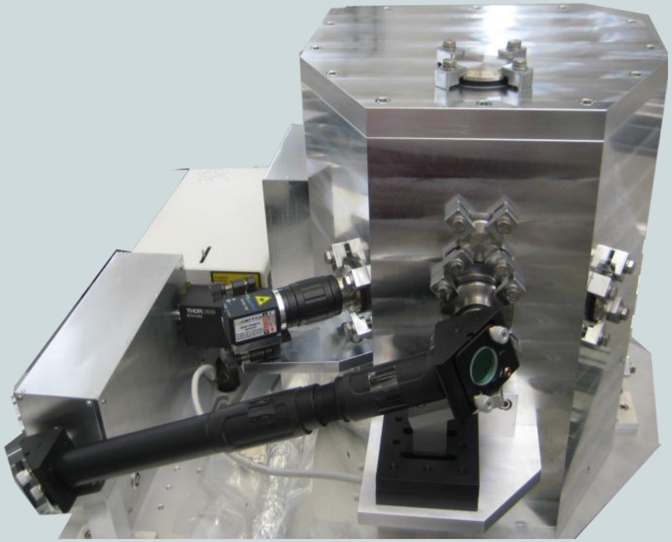


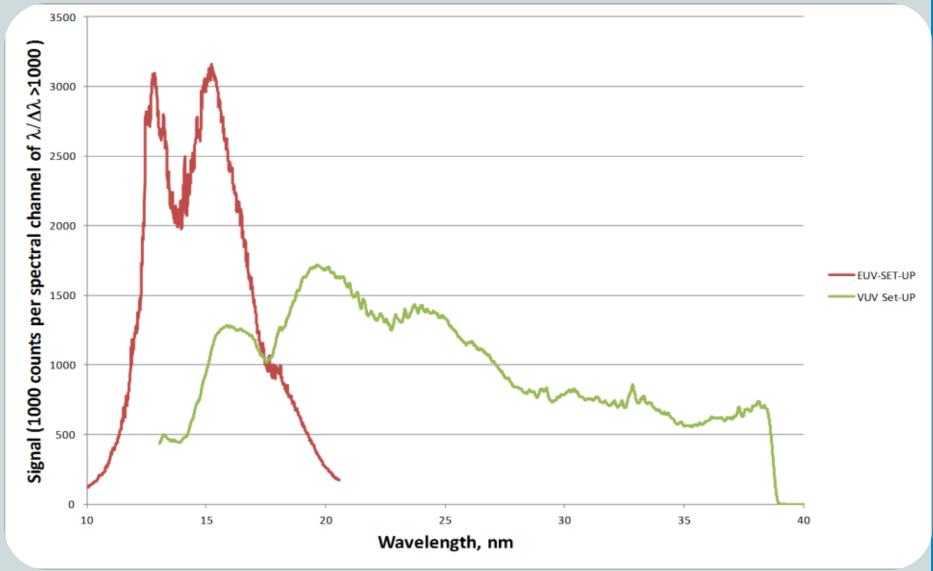
Main in-vacuum optical units of CXUVS collector module, sample stage unit and detector unit.

Can Measure:

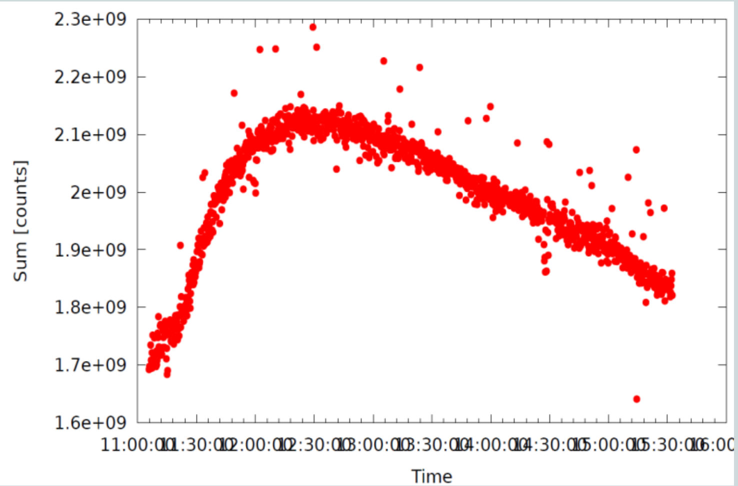
- Window / Foil transmission,
- Grazing Incidence down to < 1°
- Normal Incidence up to 85°
- Gas transmission

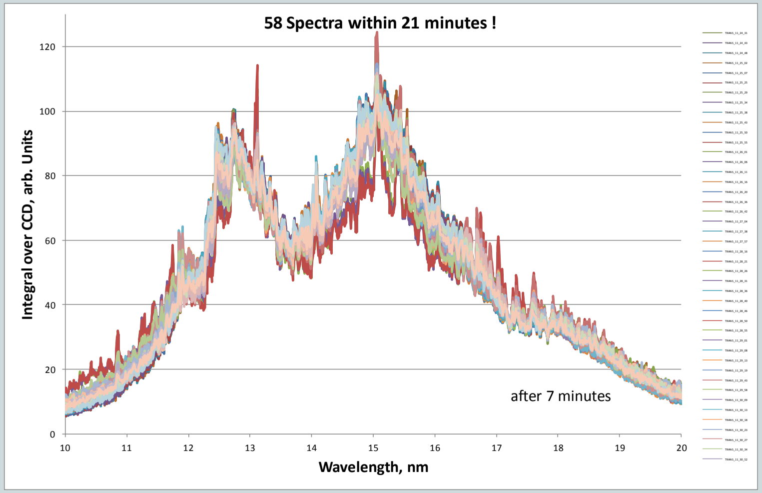
Low Power Gold LPP Source (< 5 mW EUV inband) used





LPP < 5 mW EUV i.b. for spectr.





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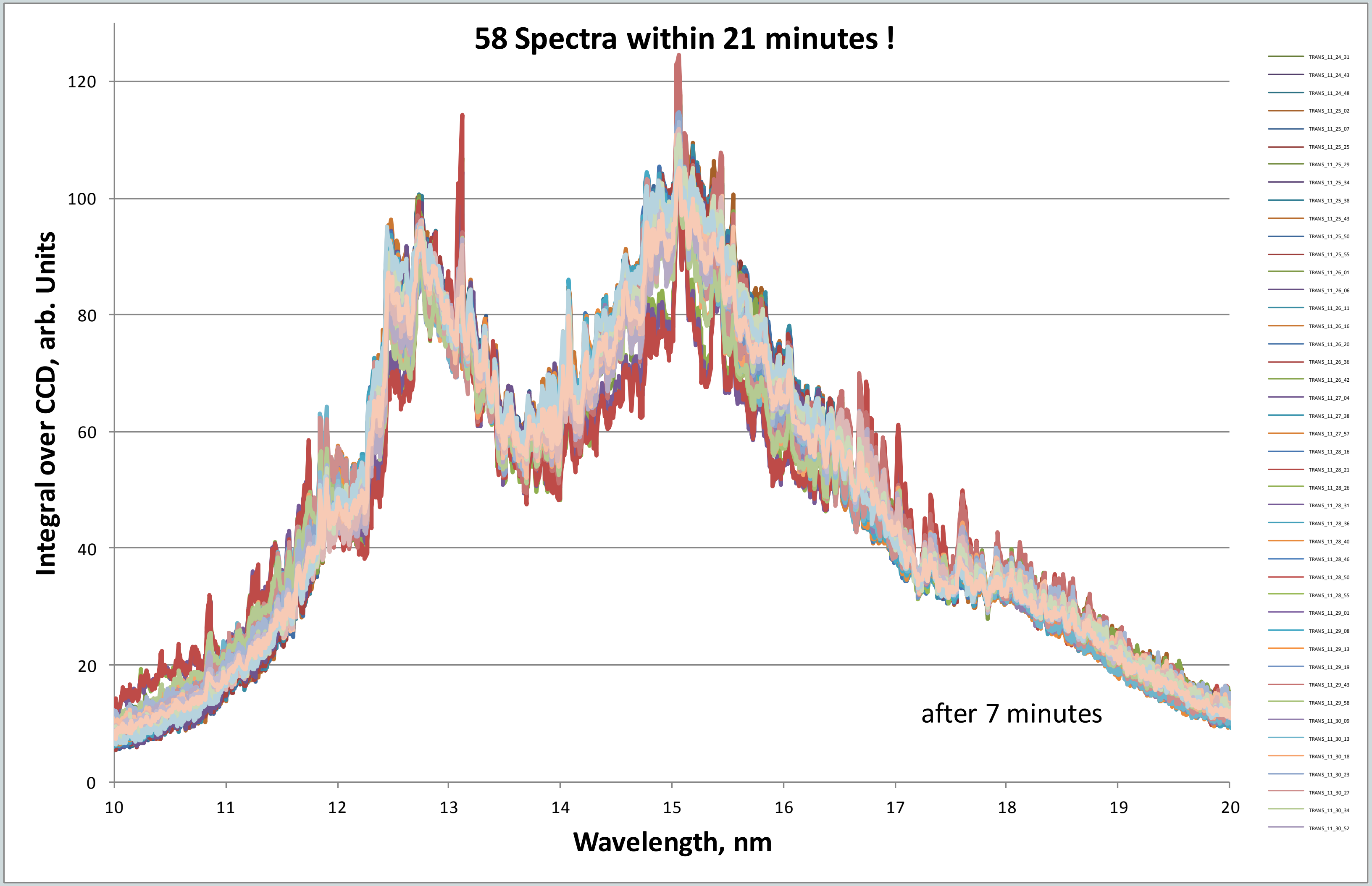
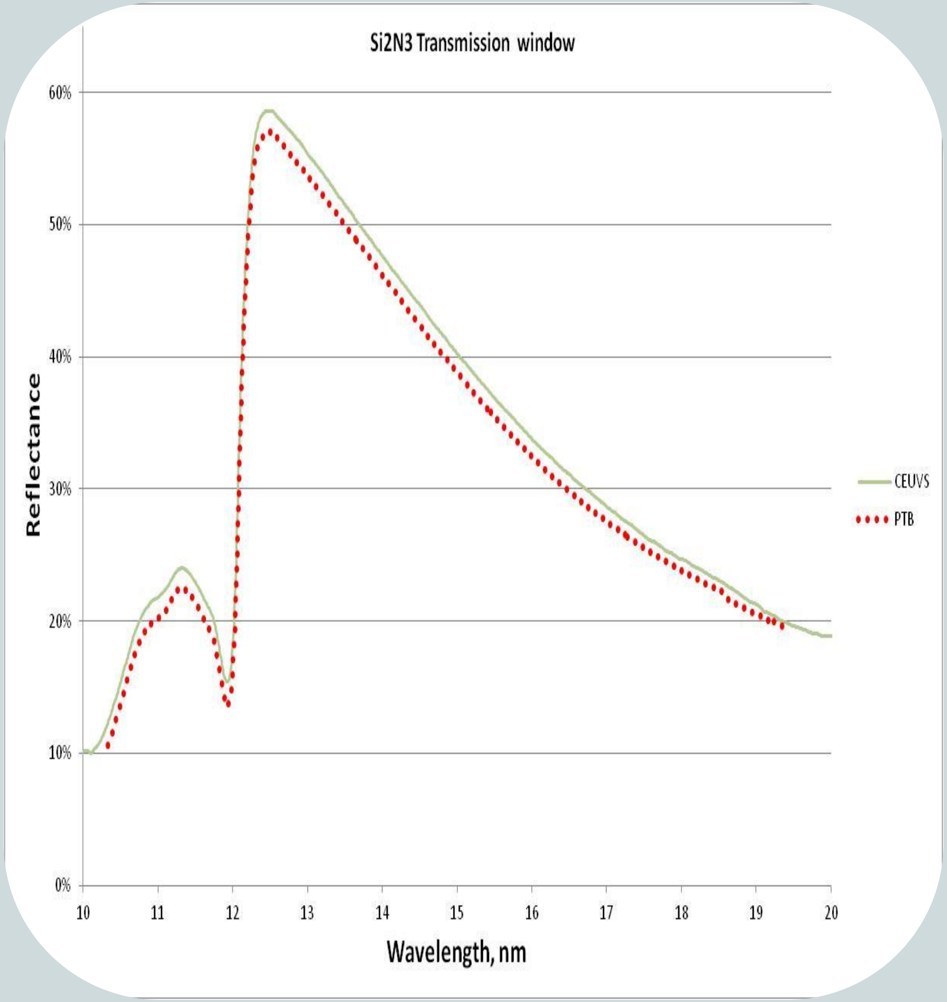
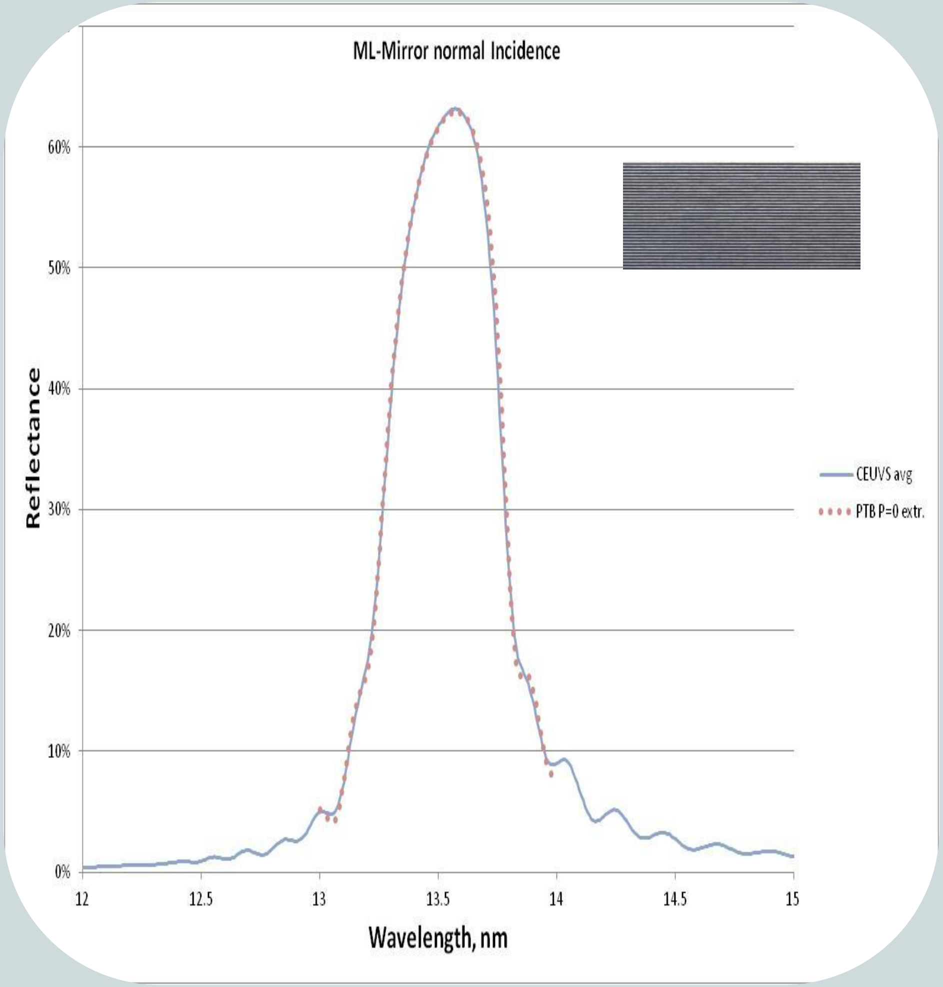
GOLD LPP Spectral Fluctuations



CEUVS example: 1 min exposed 50 µm diameter spot
Compared to PTB: MADT < 1 % absolute





ML Reflection and transmission of Si-nitride windows, compared with the measurement on the same samples at PTB

X-ray Microscopes
(“Water window” 2.4 < λ < 4.4 nm)

Experience with the demands of Mask Metrology
(Source & Optics Integration and Alignment; Nanometer Sample Positioning, UHV, Mechanical Stability; Vibration controlled architecture, Detectors etc.)

- German Research Network (Coordinator: Bruker ASC)
- High brightness LPP and DPP sources
- Grazing incidence, multilayer, and diffractive (zone plate) optics
- Resolution ~30nm, ~20µm field
- Tomography, Cryo

Bruker ASC

ACCEL

Results from X-Ray Microscopy

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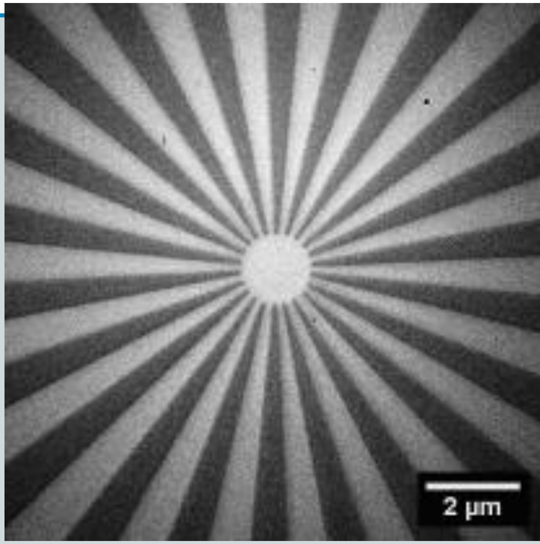
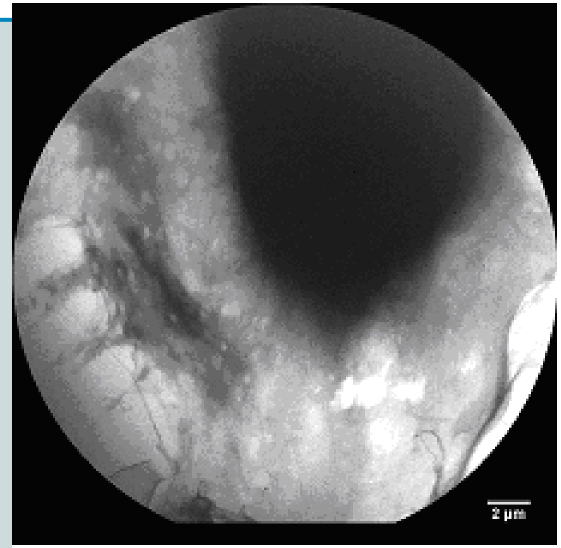
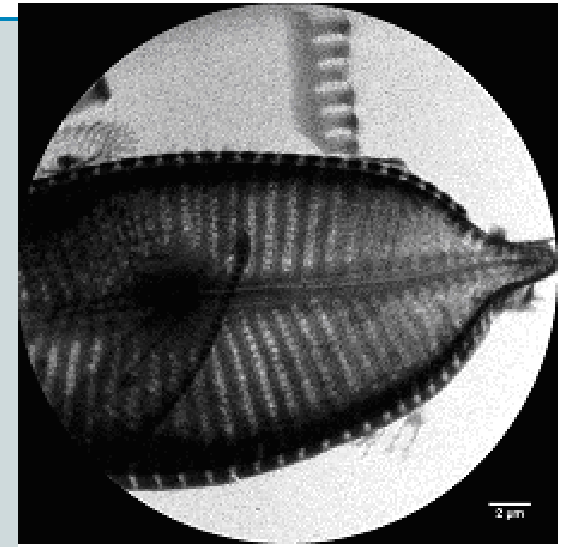
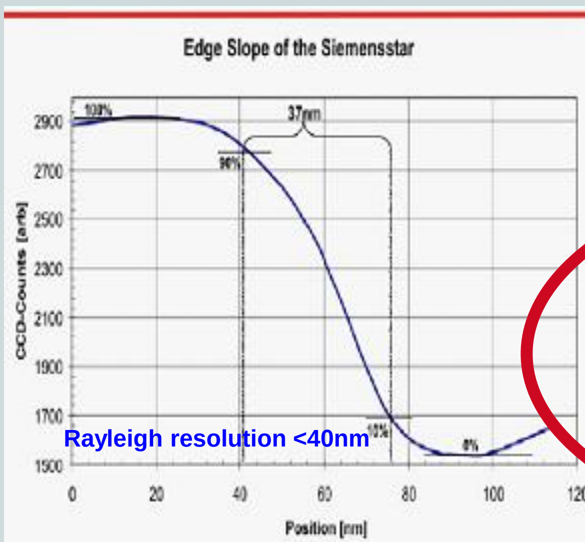






1000 x magnified diatoms



40 nm Rayleigh Resolution demonstrated

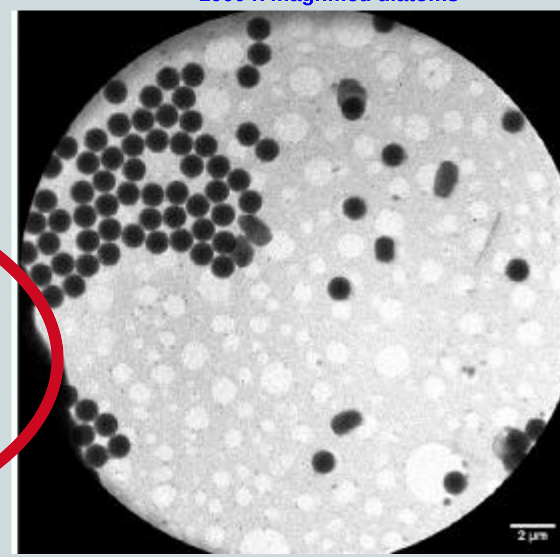
Single Line (< 0.5 % bandwidth) brightness of

- **7 W/mm²/sr with DPP**

and

> 60 W/mm²/sr with LPP

achieved



M. Benk, K. Bergmann, D. Schäfer (2008)

1000 x magnified diatoms and 80 nm latex spheres

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Imaging: EUV Transmission Microscopy Since 2005

BRUKER

CCD

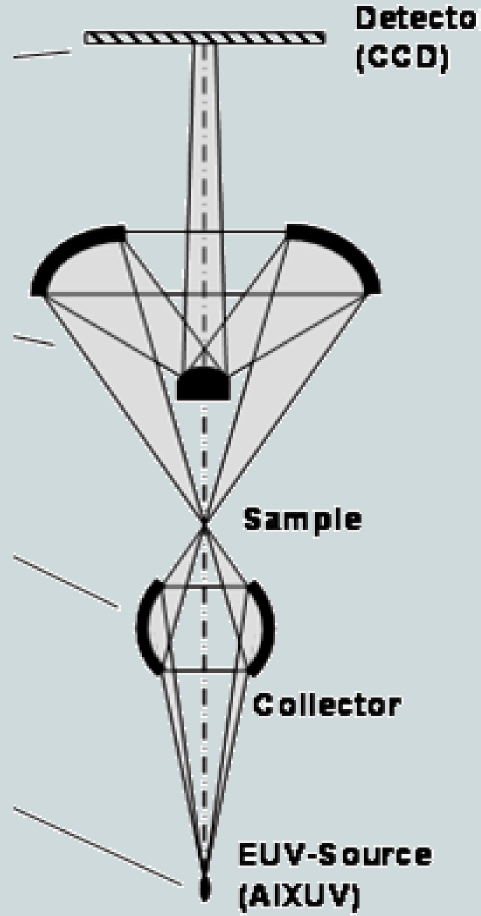
Objective

Sample Chamber

Collector

Beamline

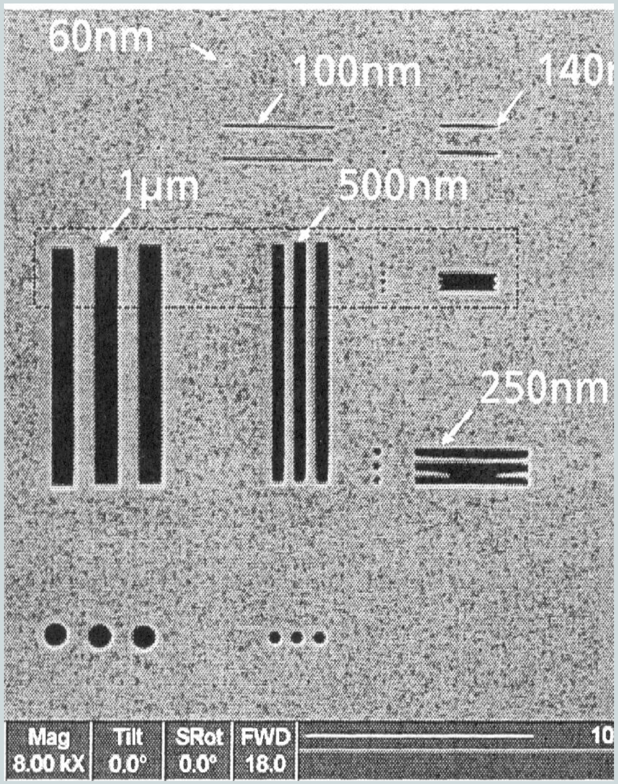
EUV-Lamp



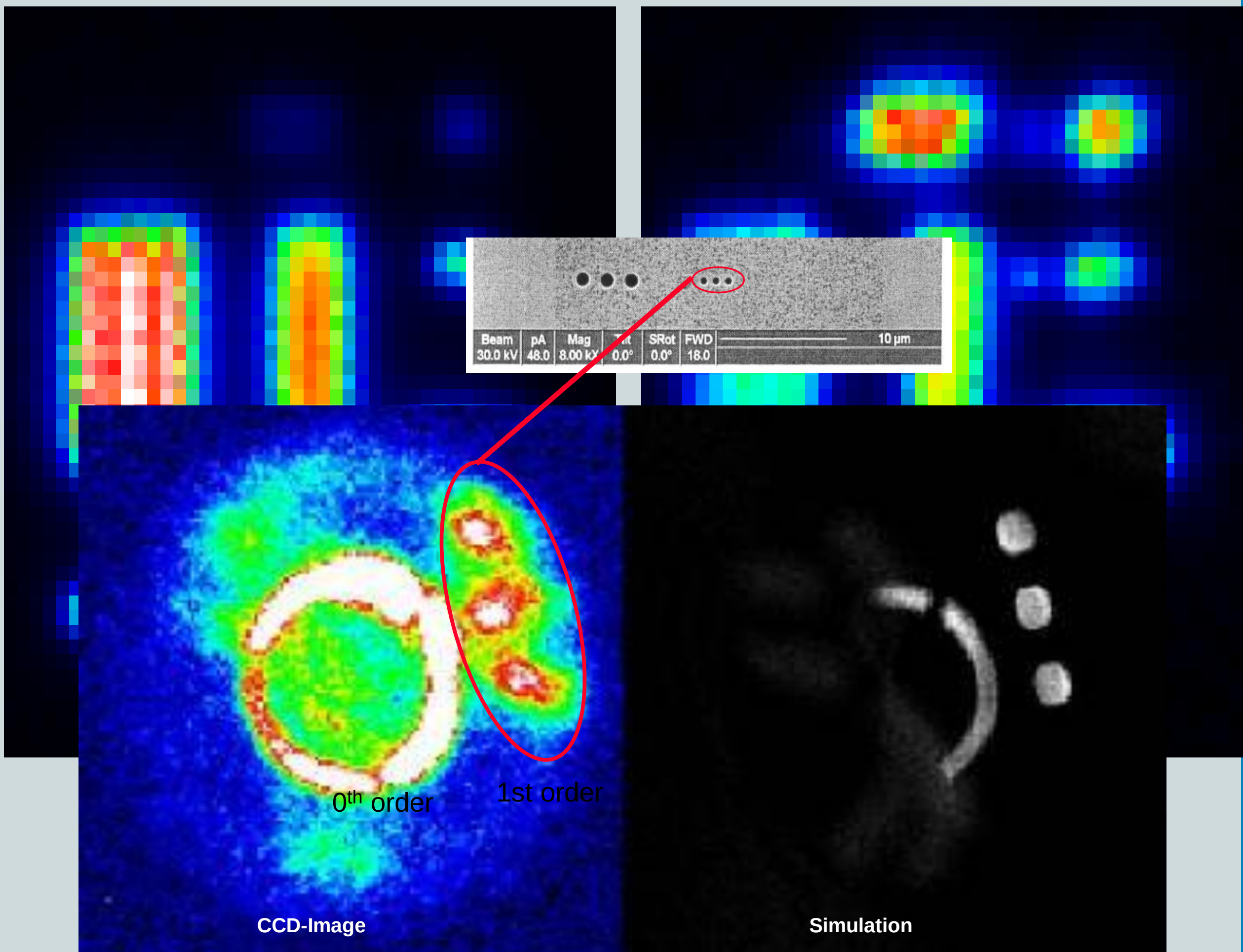
Designed for NA = 0,2 ;
i.e. < 100 nm resolution

Dark Field Transmission EUV-Microscopy since 2007

BRUKER

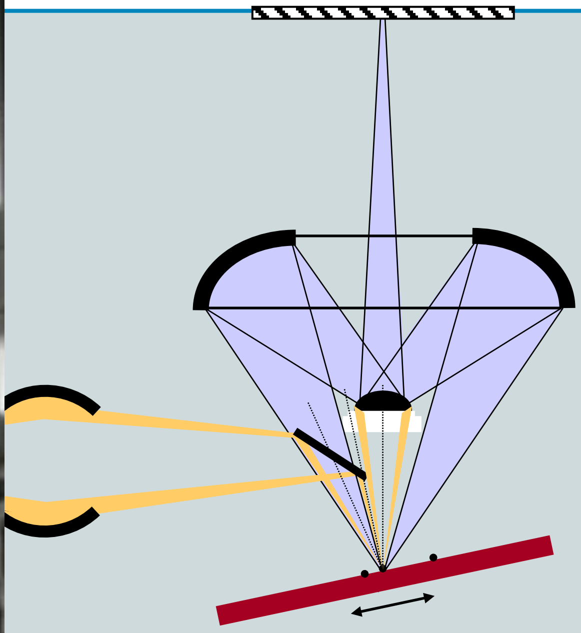


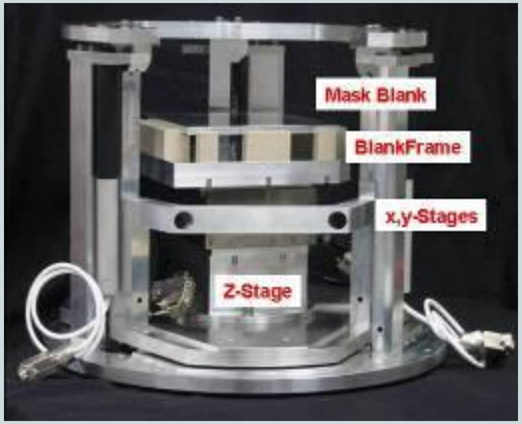
E-Mik



Small structures below 250 nm exhibit significantly higher contrast in EUV dark field images compared to 1 µm and 500 nm structures

Modification: Reflective Mode for Mask Blanks





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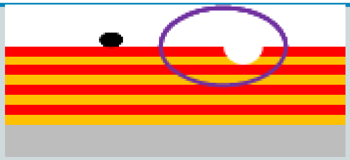
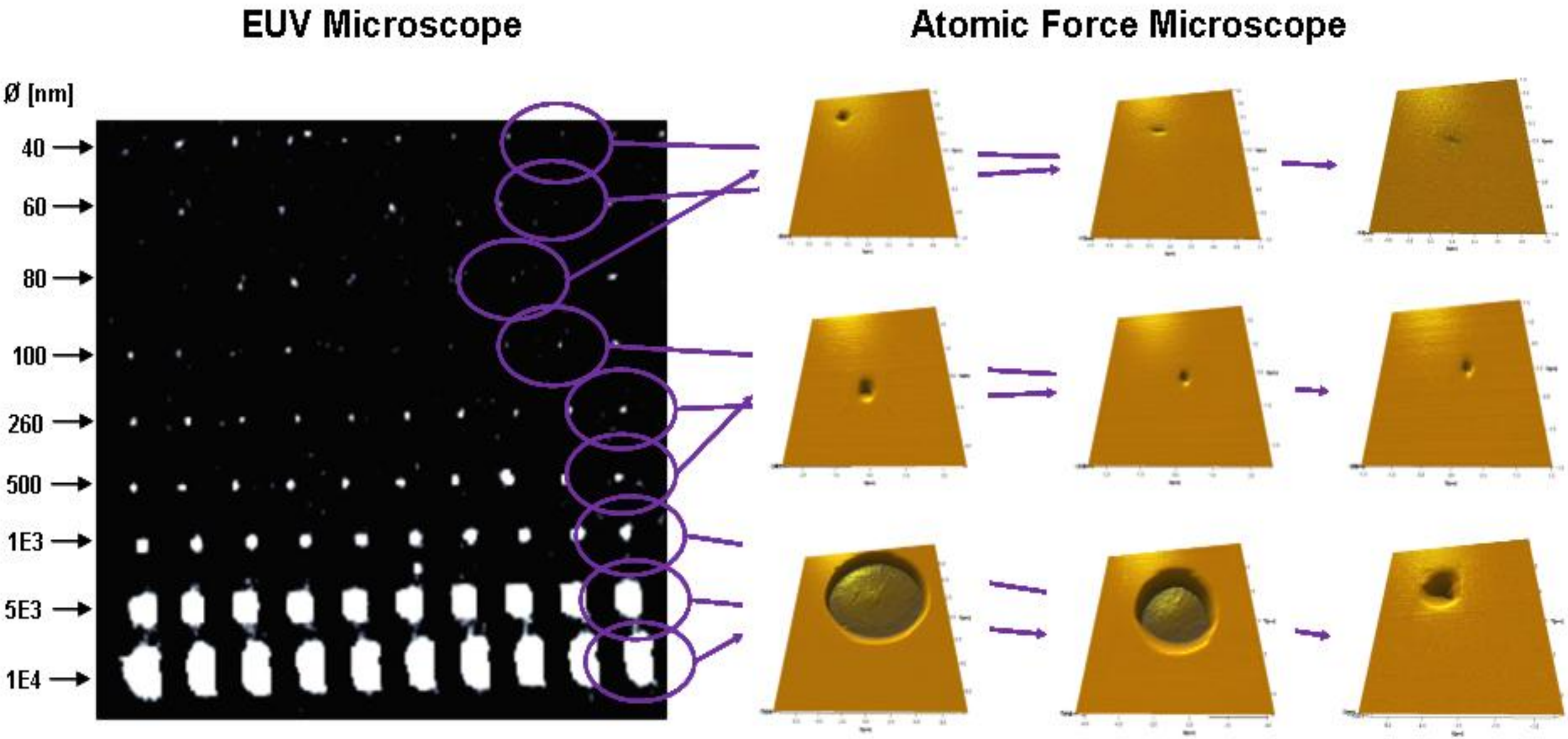
First Results on “programmed” defects on ML

Structured pits on a multilayer mirror:





Stefan Herbert

Actinic Defect Inspection fundamentals:
Result PoP Experiment

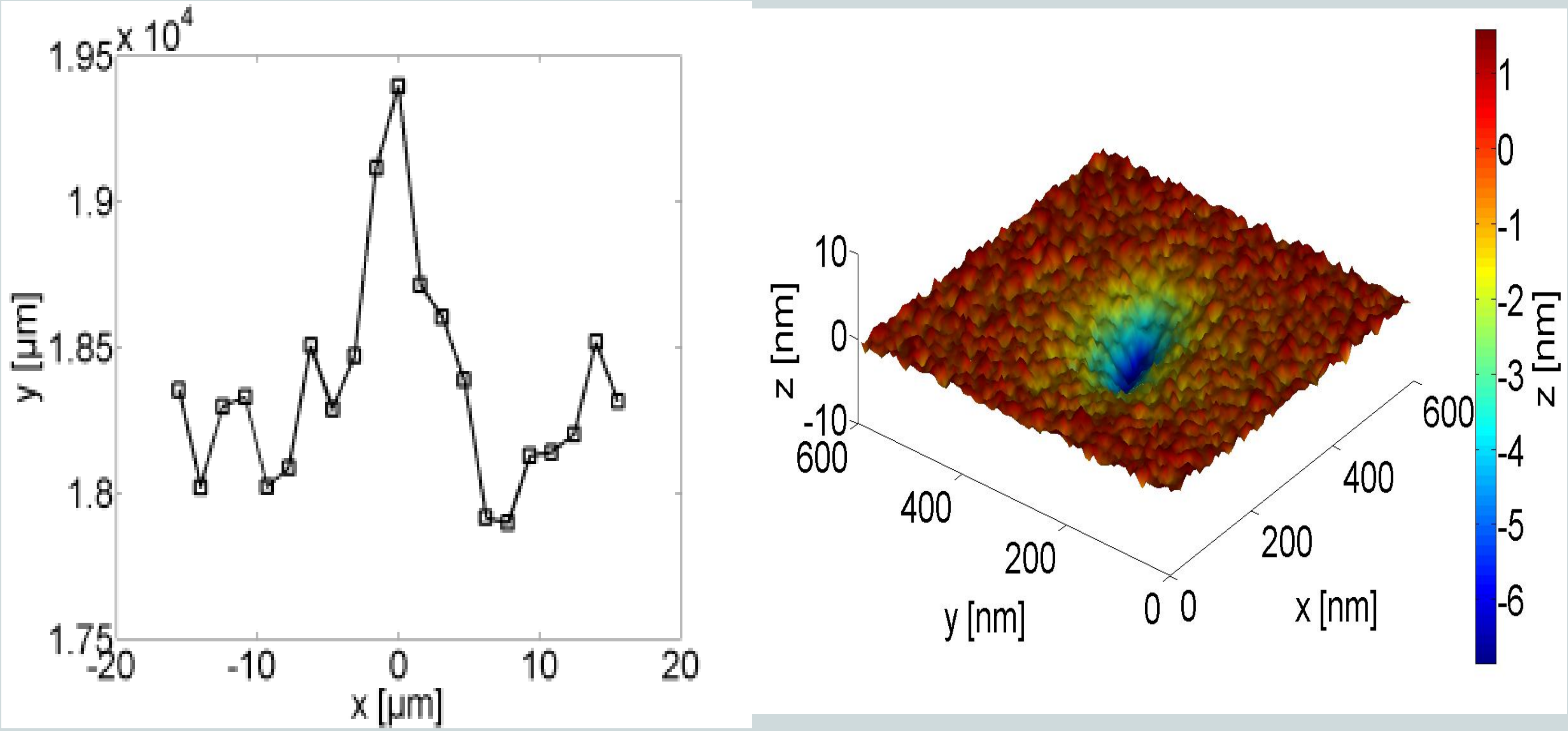


Fig. 2 : Profile of a dark field EUV image of ML mirror sample (left) and the corresponding AFM scan (right). The equivalent sphere diameter is 45 nm, the height is 7 nm.

Actinic Defect Inspection fundamentals: R&D Grade ABIT in Operation

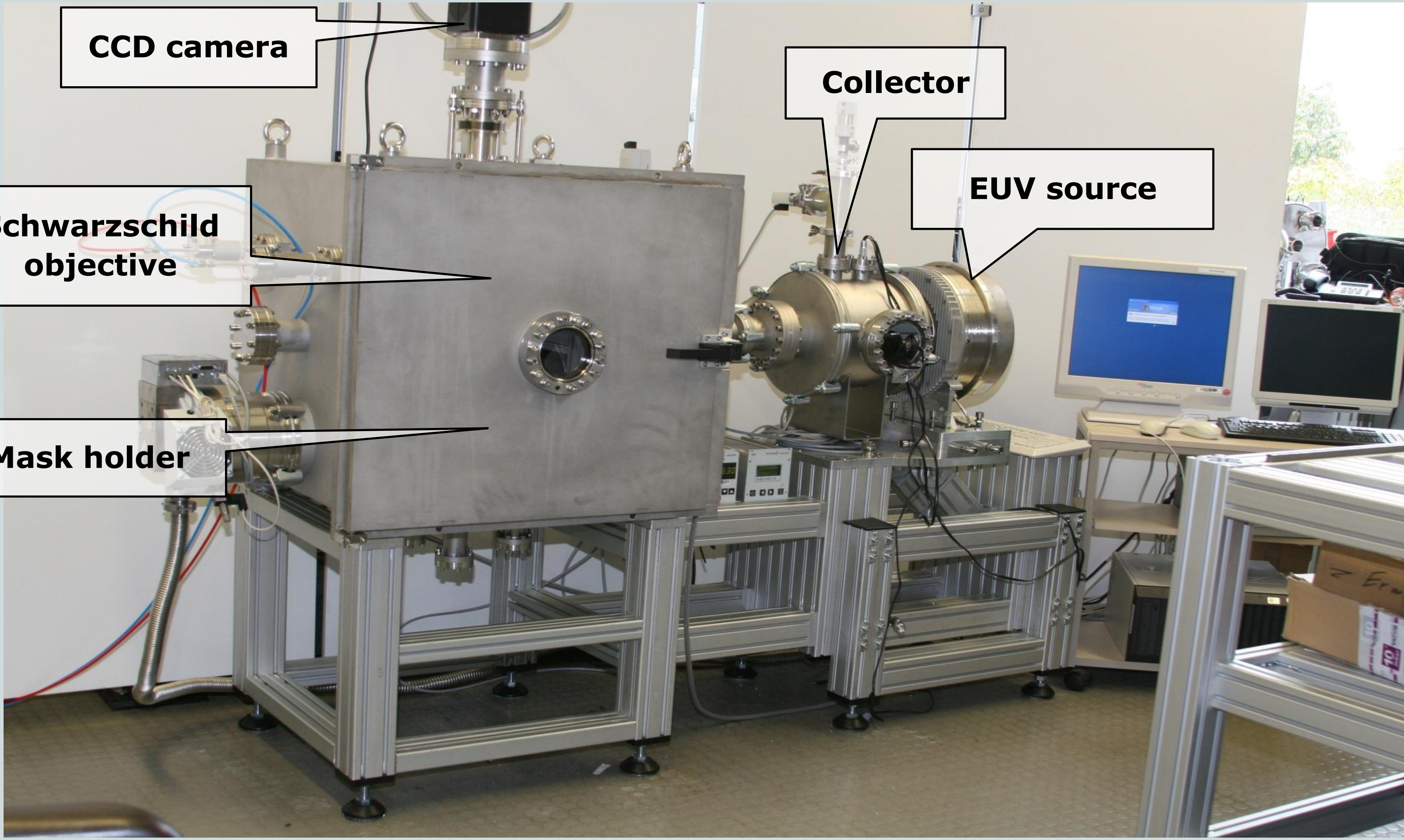
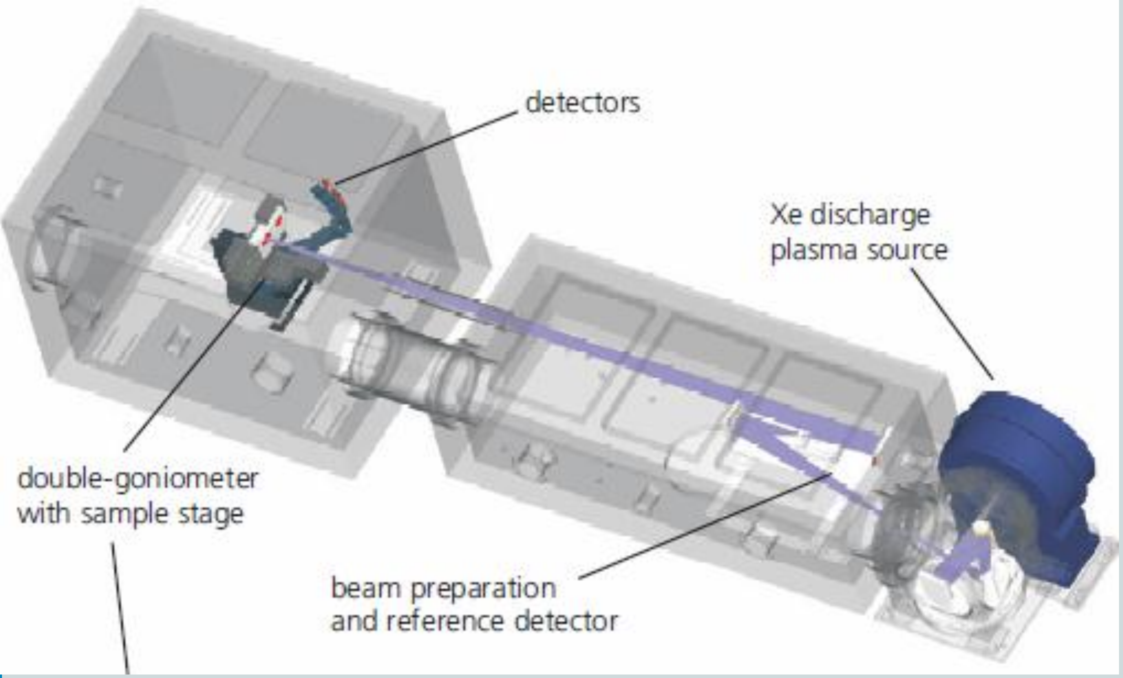
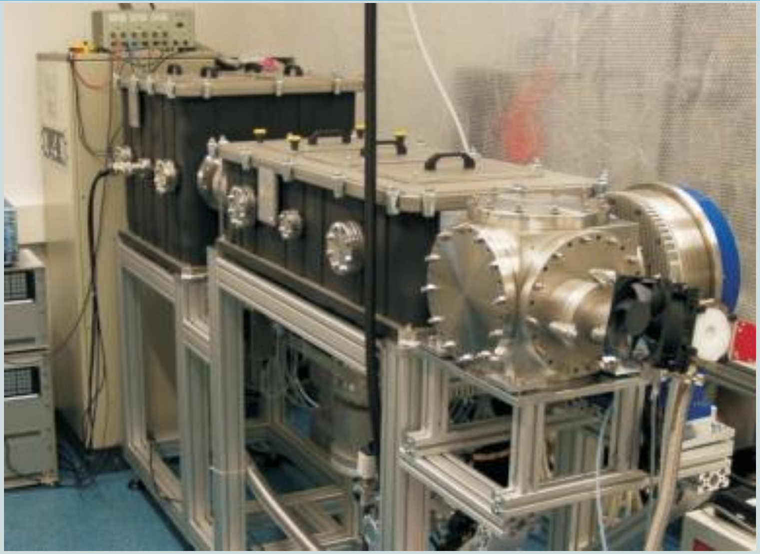
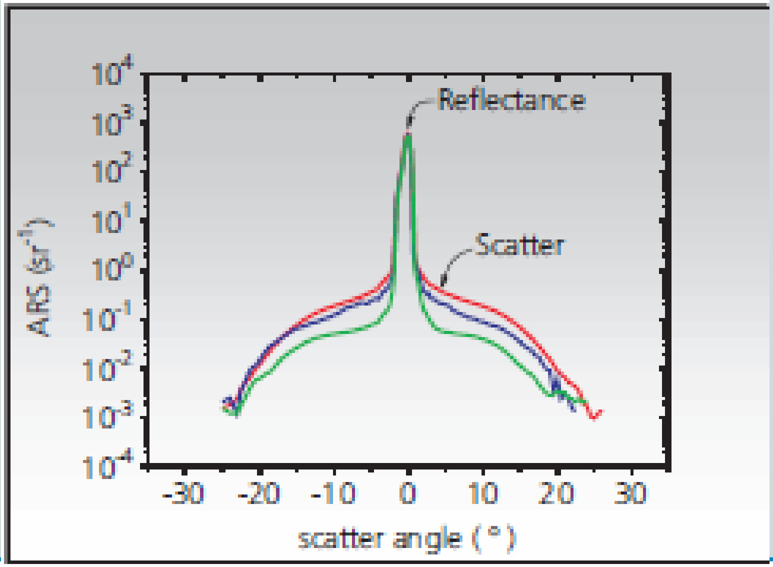


Photo of the R&D ABIT as in operation

Instrument for the Measuring of EUV Reflectance and Scattering - MERLIN



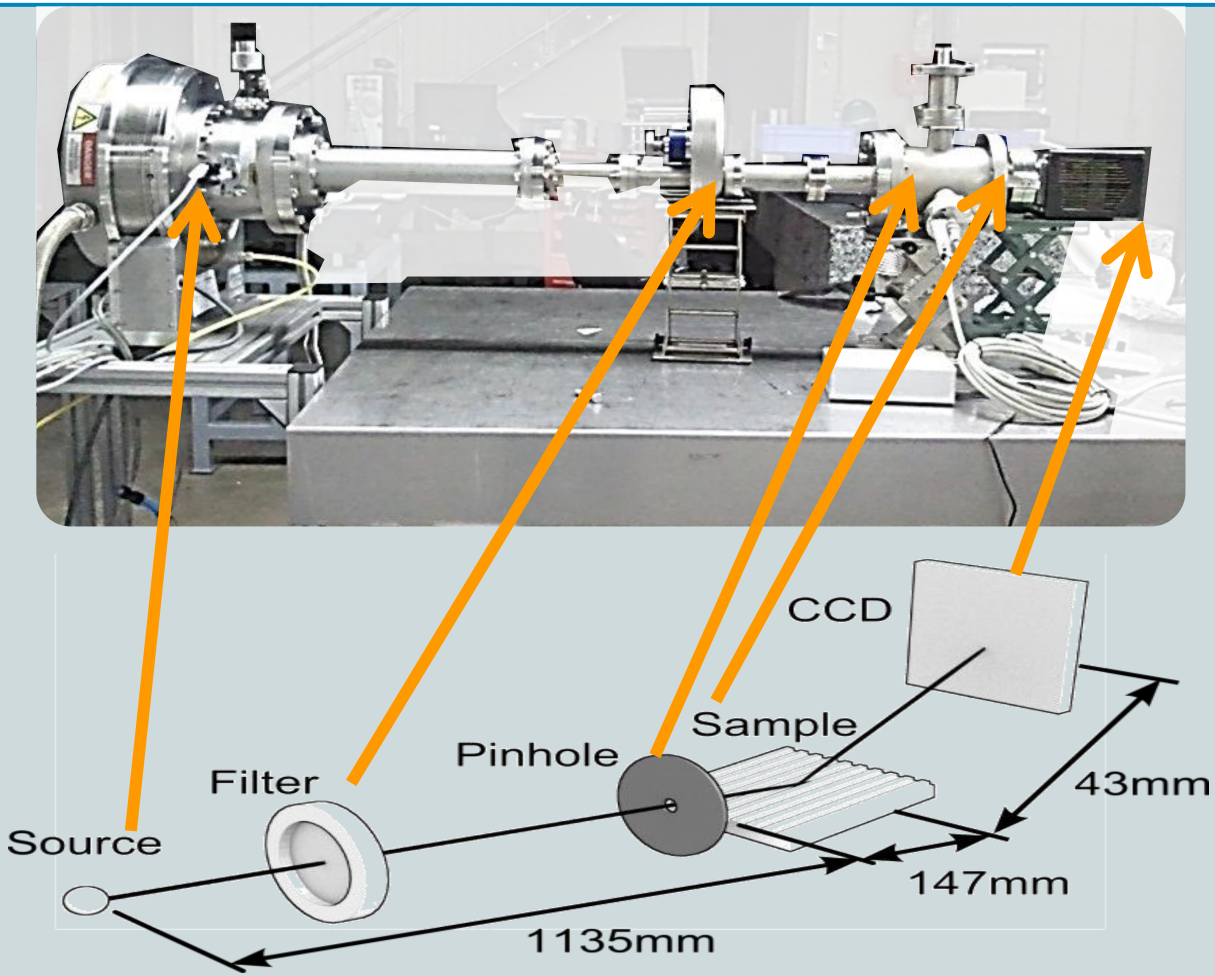




MERLIN
MEASUREMENT OF EUV REFLECTANCE AND SCATTERING

Bruker ASC

Proof of concept for
Wide Angle XUV GI Scatterometry



< 1mm² spot

>5° AOI

< 10 s per image

No beamstop

Wavelength and spectral distribution flexibility of EUV-Lamp with different working gases

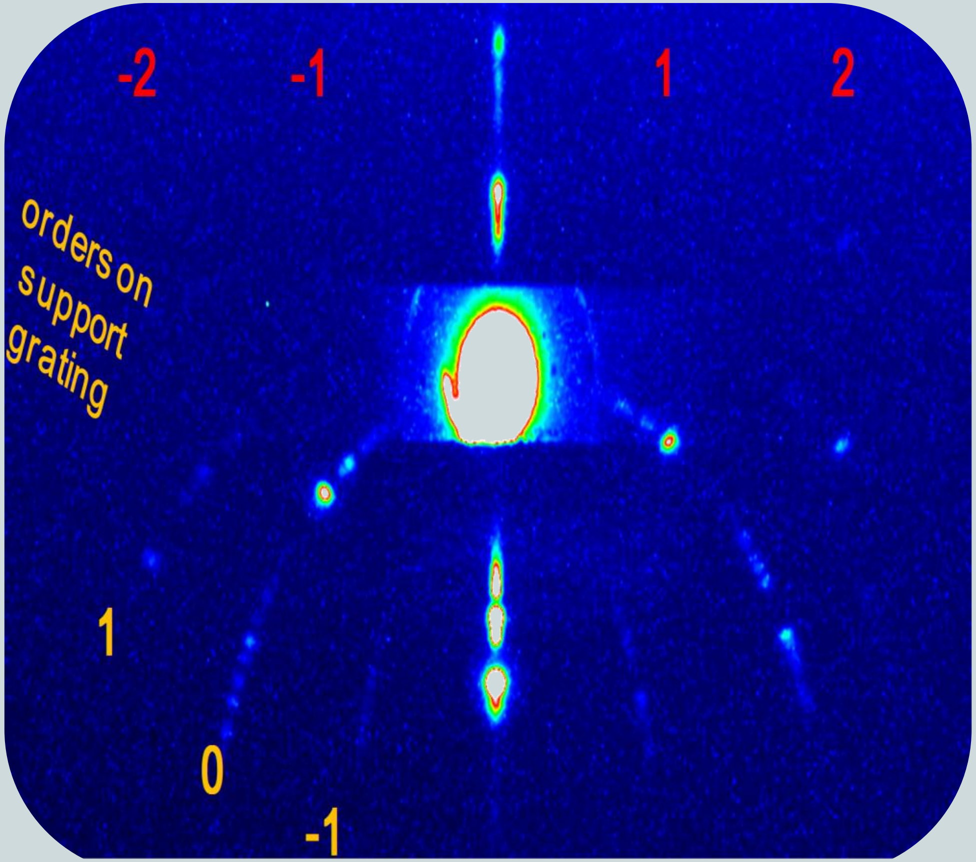
➔Achieved:

Accuracy of CD < ± 2 nm

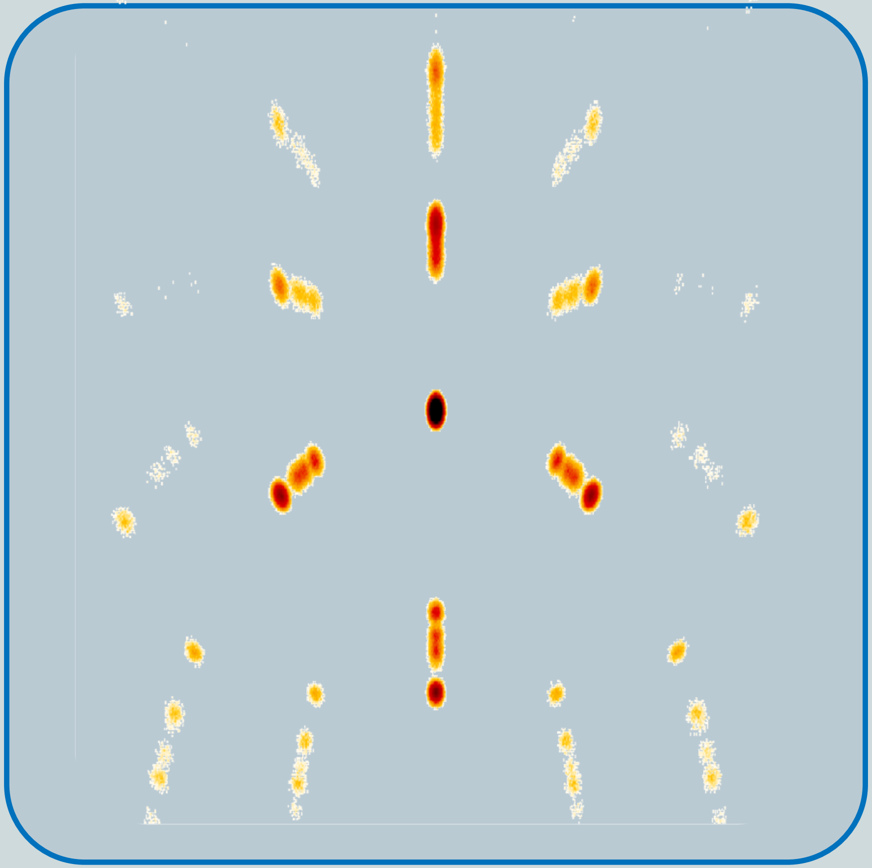
Reproduc. < 0.06 nm rms
< 0.2 nm PV

Straight forward compact Proof of feasibility experiment set-up with available lab components at BASC.

CD-WA-XUV-Scatterometry: First results

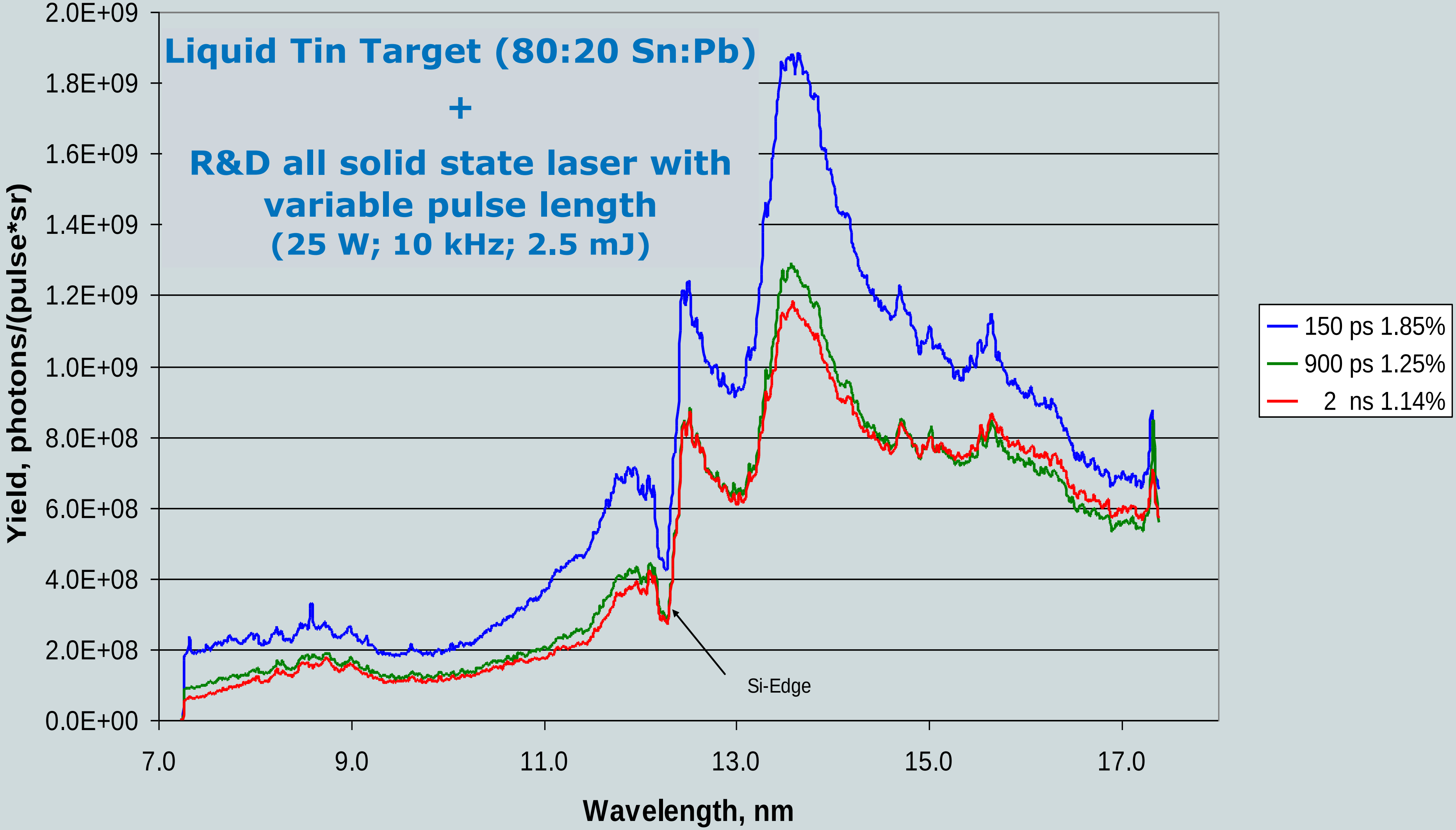


Typical Result obtained with PoP set-up



Simulation of expected result is in agreement

PoC EUV Source with minimum pulse energy; flexible Laser



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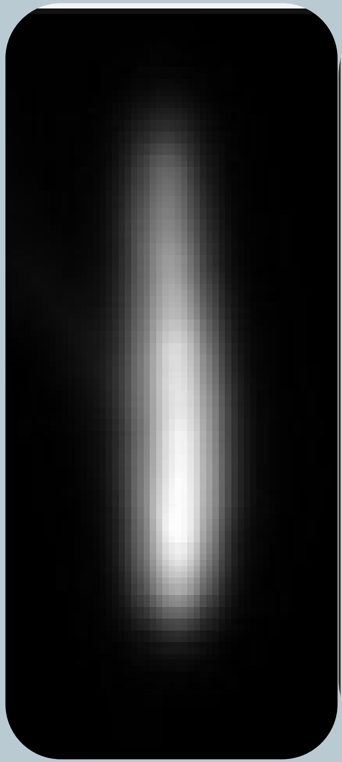
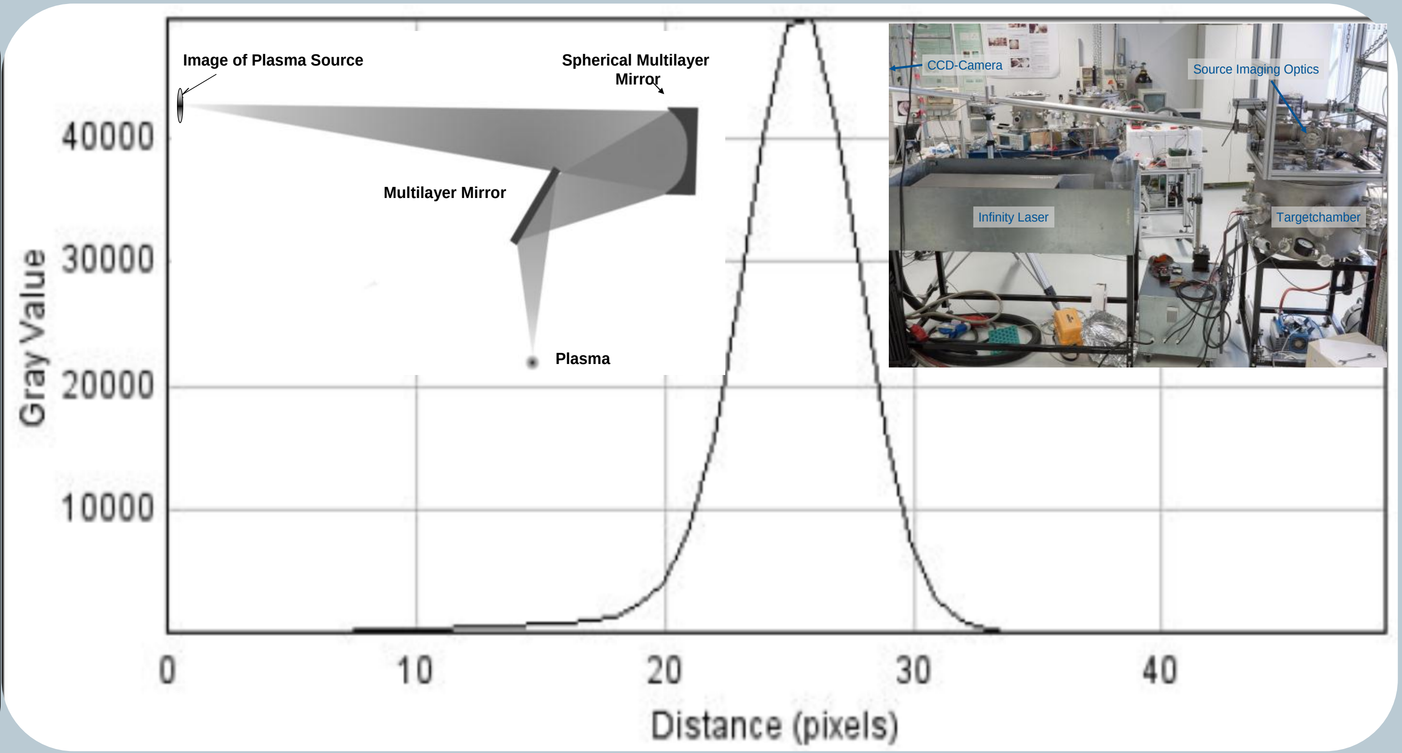
Outlook: HB source Investigation: Potential for > 300 W/mm²/sterad





9 times magnified inband EUV-Image of source and horizontal profile on CCD with 20 µm pixel. Schema of set-up and in RAC-Lab as insert.

ssion of configurations matched to customer's demands for actinic mask metro

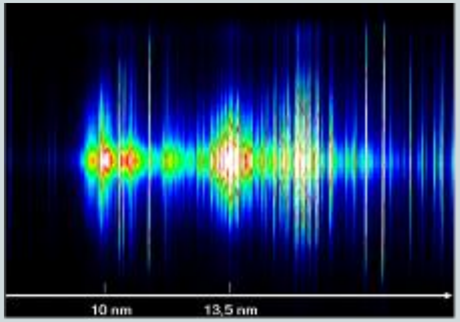
Summary : EUV Solutions with lab sources

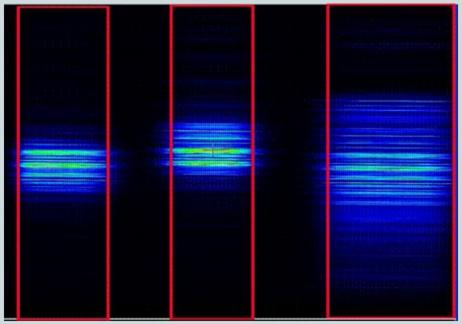
EUV-Sources

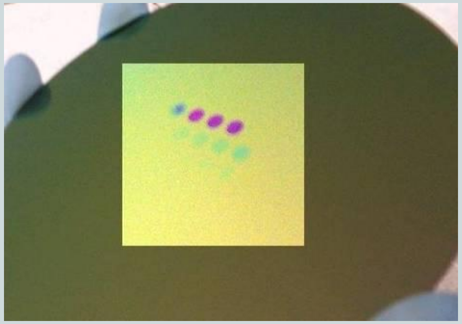
Mask Tools

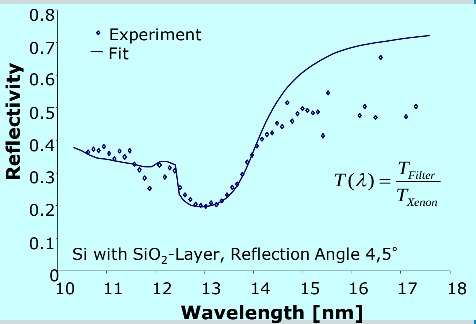
Resist Tools

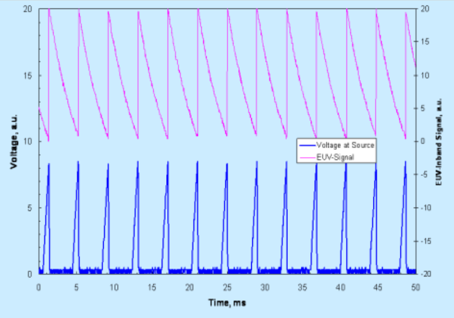
Nano Tools

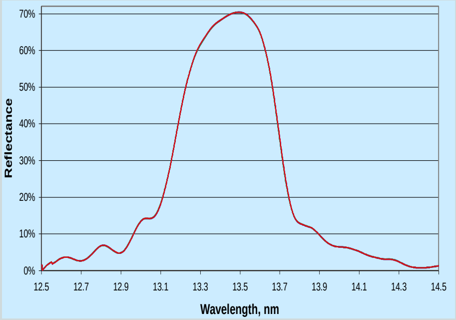


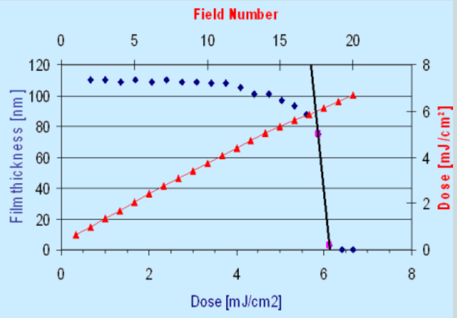


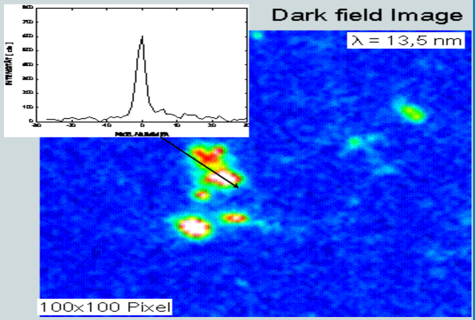


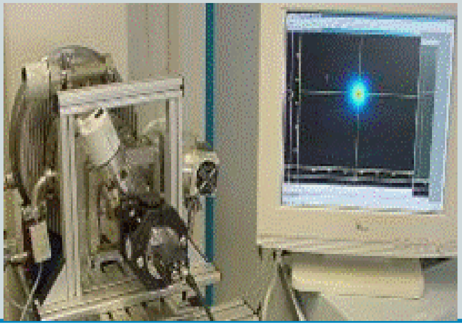


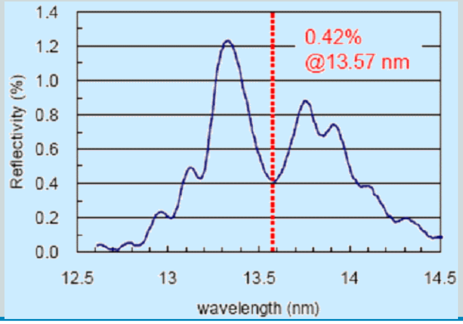


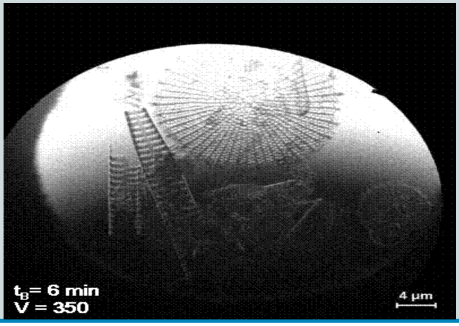












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Thank you for your attention

We gratefully acknowledge funding from the BMBF

In the framework of the Catrene (13N10572, CT301, EXEPT")

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